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# Analysis of the Impact of Delaying Compliance with 1977 Water Quality Standards

Mathematica, Inc, Philadelphia, Pa

Prepared for

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MATHEMATICA, INC
REGIONAL AND ENVIRONMENTAL STUDIES GROUP
*An Equal Opportunity Employer, M/F*

October 8, 1974

# ANALYSIS OF THE IMPACT OF DELAYING COMPLIANCE WITH 1977 WATER QUALITY STANDARDS

by

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# ABSTRACT

This report presents the results of a project designed to evaluate the relationship between the total cost of water pollution control and the date of compliance with the water quality goals specified in the 1972 Federal Water Pollution Control Act Amendments (FWPCAA). It includes a description of the major parameters that affect the cost of a specific water pollution abatement program, an analysis of recent trends in the values of these parameters, and presents a methodology for analytically estimating the cost of water treatment for individual industrial discharges.

The project included two case studies. The first examined the potential to reduce total waste treatment costs by implementing a regional waste treatment system in the Meramec River Basin in Missouri. The second examined the changes in initial capital investment and life cycle waste treatment costs, as a function of time in the Grand Calumet River and Indiana Harbor Ship Canal in Indiana.

The case studies indicated that significant savings can be achieved by allowing delays in compliance for up to three years from 1977 to 1980. However, savings are only possible in water quality limited stream segments (those stream segments which do not meet stream water quality standards when the effluent standards specified in the 1972 FWPCAA are applied), and are only possible in basins where large regional systems can be implemented. Therefore, these savings only accrue to municipalities treating sanitary wastes and minor industrial wastes. In general, no significant savings result from delaying compliance by large industrial dischargers, where on-site treatment is generally required. Maximum savings resulting from a three year delay in compliance can range from $770 million to $2,580 million.

It was recommended that EPA develop specific criteria to be used in evaluating whether or not a delay be granted, that a set of guidelines be established for use by local agencies in requesting delays and that an institutional structure be established to review and approve or reject requests for delays.

This report was submitted in fulfillment of contract number 68-01-2454 by MATHEMATICA, Inc., Regional and Environmental Studies Group, under the sponsorship of the Environmental Protection Agency. Work was completed as of September, 1974.

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# SECTION I

## CONCLUSIONS AND RECOMMENDATIONS

### A. CONCLUSIONS

The project objectives were to determine how a shift in the date of compliance with the water quality standards of the 1972 Amendments to the Federal Water Pollution Control Act (FWPCA) is related to water quality and to total abatement cost. The following conclusions can be drawn from this project which included two in-depth case studies: (1) for highly heterogeneous dispersed effluents as would most likely be found from different industrial dischargers to a stream, there are no significant cost savings resulting from a three year delay in compliance with 1977 standards; and (2) for highly homogenous effluents, typical of municipal sanitary dischargers, there is a potential for significant cost reductions.

Cost savings are possible when discharges can be aggregated and treated in larger regional plants. These savings result from two factors. The first is the economies of scale associated with joint wastewater treatment. However, these economies of scale are substantially reduced by the cost of the larger interceptor network required to deliver sewage to the fewer number of treatment plants. The second factor is the decrease in the requirements for Advanced Waste Treatment (AWT) as larger regional plant discharges can be cited at streat segments with a greater natural assimilative capacity.

This second factor can result in significant overall savings in water quality limited stream segments* where AWT may be required. While in effluent limited segments** where only secondary treatment of municipal wastes and Best Practicable Treatment (BPT)*** of industrial wastes is required, this second factor does not contribute to cost reductions.

In the case study of the lower Meramec Basin, regionalization resulted in a 70% decrease in the initial capital cost of AWT and a 24% savings in the total life cycle cost of meeting the 1977 goals.

In the 1973 "Needs" survey as reported to Congress (Ref. 43) EPA estimated the cost of construction of municipal treatment and collection facilities which were eligible for Federal funding under the 1972 Amendments. Total costs were estimated to be over $60 billion, of which $5.6 billion was required for AWT. Using this EPA data and data collected in a MATHEMATICA survey of EPA regional offices, it was estimated that of the $5.6 billion required for AWT, a maximum of $770 million to $2,580 million could be saved by selectively delaying compliance with the 1972 Amendments.

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* Water Quality Limited Segments are defined as those stream segments for which the application of effluent standards as specified in the 1972 FWPCAA does not achieve water quality standards. Treatment above the levels specified for effluent limited segments is required.

** Effluent Limited Segments is defined as those stream segments which meet instream water quality standards through the application of secondary level treatment to publicly-owned wastewater works and BPT to privately-owned wastewater works.

*** Best Practicable Treatment is defined as that treatment level resulting from the application of the general average of the best existing control technology.

## B. RECOMMENDATIONS

MATHEMATICA, Inc. recommends that EPA establish a process whereby local authorities can be granted variances from complying with the schedule established in the 1972 Federal Water Pollution Control Act Amendments (FWPCAA) when such delays result in significant cost savings. Because not all water quality limited segments will be able to achieve cost reductions, it is recommended that no across-the-board variances be granted.

States should be granted extensions only upon presentation of evidence by the state which demonstrates:

(1) that the state has developed a plan for compliance with the 1977 standards by July 1,1977;

(2) that there are treatment alternatives available which result in significant life cycle cost savings over the plan proposed for 1977 compliance;

(3) that the implementation of the less costly alternative cannot be completed by 1977 by providing an implementation schedule resulting in full compliance; and

(4) a statement of the adverse and beneficial environmental consequences of the delay.

Studies required to determine whether or not an extension will result in cost savings are themselves expensive and there is no assurance that a net benefit will be the result. Therefore, it is necessary to develop a set of guidelines which can be easily used by local personnel to determine whether a more expensive study is warranted. Therefore, in order to encourage states to request appropriate extensions, EPA should develop a set of guidelines and estimating techniques which states can utilize to determine if a request for a variance should be investigated in depth.

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# SECTION II

# BACKGROUND

## A. THE 1972 FWPCAA

Title III of the Federal Water Pollution Control Act Amendments (FWPCAA) requires that all dischargers achieve specified levels of discharge treatment by 1977 and 1983. The Act specifies that at a minimum, publicly owned treatment works treat to secondary levels by 1977 and "best practicable waste treatment technology" (BPT) by 1983, and that other than publicly owned treatment works apply "best practicable control technology currently available as defined by the Administrator" (BPT) by 1977 and "best available technology economically available" (BAT)* by 1983. In addition, treatment to levels greater than those specified above is required when "necessary to meet water quality standards or schedules of compliance." Standards of performance of BPT and BAT are developed and promulgated by EPA, while water quality standards are generally set by the states.

Section 317 of Title III directs that there be continued studies of alternative methods of financing the cost of water pollution control. In analyzing financing alternatives, many different parameters must be investigated among them: the source of funds; including Federal, state or local taxes, state and local bonds, private financing from either long term debt or operating revenues; the relationship between needs for pollution control and other social needs; national economic policy and conditions;

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* Best Available Treatment is defined as generally the treatment level resulting from the application of the best existing control technology which is capable of being designed though not yet in place.

and the actual timing of such investments. This report addresses this last point. Through case studies, the relationship between the timing of investments in water pollution control and the resulting cost of such investments has been investigated. However, prior to describing these case studies, it is first necessary to review the required levels of water treatment.

By 1977 public dischargers must implement secondary level treatment of all discharges, while non-public dischargers must implement BPT and in addition must pretreat discharges to public treatment works for removal of those pollutants which are not susceptible to treatment by such works or which would interfere with the operation of such works. These are minimal treatment requirements, for there is the requirement that additional treatment be implemented when the above levels do not assure the water quality in the stream or river meets local, state and/or federal water quality standards.

Waterways where water quality standards are achievable under the minimal levels of treatment as specified for 1977 are termed as "effluent limited". In other words, the application of effluent standards will result in the achievement of water quality standards. Those segments where the application of only effluent standards will not result in the achievement of water quality standards are termed "water quality limited" and additional wastewater treatment is required.

The level of treatment required of each discharger into a water quality limited segment is usually determined on the basis of a load allocation study. The Amendments require that the state identify and designate water quality limited areas and then allocate loads to all dischargers to satisfy the water quality standards. The load allocation study requires the use of a stream water quality model and a cost minimization procedure or algorithm to determine the distribution of discharge loads which meets water quality standards and which requires the least cost. One such model, MULQUAL, developed by MATHEMATICA, satisfies these requirements and was used for the case studies described in a subsequent section of this report. It should be emphasized that load allocation studies are required only on those stretches of water where effluent treatment standards do not result in a stream quality which meets water quality standards, and that loads are allocated to both public and non-public dischargers. That is, private and public dischargers may be required to treat to levels greater than minimums specified by 1977. The basic criteria for allocated loads are minimization of cost and equity of the resultant cost schedule.

## B. THE PROBLEM OF INVESTMENT TIMING AND COST

There are several factors which influence the total cost of any water quality project or program. Many of these factors are attributes of the particular project such as the functional or performance requirements, the size of the project, the particular type of equipment required and the desired water quality standards. Other factors which influence cost are determined exogenously to the particular project and include the interest rate on debt, inflation rates prior to construction and the influence of competing demands for construction financing. Finally, there is a third set of factors which come to bear when water quality projects must be implemented in a short time period. These factors include premium prices required for rapid delivery and/or overtime and second shift operation, premature replacement of equipment and inability to implement the most cost effective treatment processes within the required schedule constraints. Thus there are several controllable and uncontrollable factors acting at both the national and the local level to establish a total cost for water quality programs.

As pointed out above, the FWPCAA required specific water quality achievements by 1977 and 1983. The cost of the investments required to achieve these goals is in part determined by these compliance dates. The development of a relationship between the total cost of control and the timing of the actual investment is the objective of this study.

There were several important considerations in the development of an analytic framework for the conduct of this study. These are discussed in a later section, but it is helpful to introduce one factor at this point.

Alternative water quality improvement programs can be developed to meet any specific goal. These alternatives can be compared and ranked and on the basis of some criteria of economic efficiency, equity, effectiveness or some other factor or combination of factors, a "best" alternative can be selected for implementation. In order to meet the requirements of the 1972 Amendments, it is necessary to introduce a time constraint and to disregard all alternatives which cannot be implemented within the schedule specified by the Act. Once these alternatives are eliminated, the comparison and ranking procedure would lead to the identification of the "best" alternative consistent with schedule constraints. The latter "best" alternative may or may not be identical to the "best" alternative selected from the full set of alternatives. In other words, the schedule constraint may or may not require that we disregard the absolute "best" or optimal solution and accept some alternative which is optimum within the time constraints.

This report includes two different case studies. The one study (the Calumet) examines the relationship between cost and timing when the extension of the target date does not change the water quality program and the absolute "best" alternative can be implemented by July 1,1977; while the second case (the Meramec) examines a situation where the implementation of the most effective water quality program cannot be completed prior to July 1, 1977. That is the schedule constrained "best", a program that can be implemented by 1977, is not the overall "best" water quality program.

Through two detailed case studies the relationship between total cost and compliance date is analyzed. The relationship is then extended to estimate the national impact of changing the compliance date.

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# SECTION III

# TECHNICAL APPROACH

## A. THE CASE STUDY APPROACH

To investigate the relationship between water quality, total cost and compliance date, MATHEMATICA conducted two detailed river basin case studies. The basins chosen were very different; one was primarily residential, while the other was primarily industrial. They provided insights into the compliance requirements peculiar to each sector. In addition, the case studies allowed a detailed examination of total costs under a basic set of assumptions and reasonable variations about those assumptions.

The basic problems with the case study approach are that the results may not be amenable to national analysis or that the case may be so atypical as to not be generalizable. The examination of two different cases, each near the boundaries of the range of possible alternative bounds the analysis and provides insights into national impact. The selected cases provided an estimate of the maximum savings that can be incurred through delaying compliance dates.

## B. COST COMPONENTS

In order to conduct detailed case studies, it was necessary to estimate the cost of treatment for each discharge to the river. Many different factors must be considered in the estimation of these costs and some of the more significant factors are described below.

In this section the process by which cost estimates were generated is described. Each of the more significant factors is briefly described, with a statement detailing how that factor was considered in the case studies. Then the process by which these factors and available cost data were utilized to estimate the cost of treating each discharge to the stream is described and applied to a specific example.

## System Hardware Configuration

The design of the water quality program hardware is perhaps the single most important factor in determining total cost. The major components of such a system as considered in this study are interceptors, primary and secondary level treatment plants and advanced waste treatment (AWT) plants. Obviously, the cost of any treatment program will vary dramatically as a function of the length of the interceptor system, the quantity of flow, the required size of secondary level treatment plants, and the percent removal or degree of treatment required in excess of secondary level treatment.

In the case studies, the system hardware configuration was defined by the load allocation studies of the two basin studies. These studies were performed in support of the States of Indiana and Missouri and are the basis of actual allocations. These studies consider various alternatives including bypass piping, municipal treatment of industrial wastes, various levels of on-site treatment and various regional configurations in developing the least cost allocation.

A major problem in any analytic study is the estimation of total treatment train* costs as a function of the above parameters, since most cost data readily available is reported for specific plants or on the basis of a specific unit process** such as carbon absorption or breakpoint chlorination or unit operations***.

The solution to this problem was to utilize cost data as reported for known process trains which were developed to treat specific effluent discharges. Such data was found for many industrial processes as an output of the EPA program to develop industrial waste treatment standards for industry. For municipal costs, specific trains were utilized which combine various unit processes to achieve different levels of treatment. Again, EPA reference data was utilized.

The EPA data was used for several different reasons. First, It was felt that this data was the best cost data currently available, reflecting the most recent research and cost trends. Second, the data was the most widely used and, therefore, readily available to support other studies which might apply the project results to other individual cases. Third, and most importantly, the costs were based on the actual treatment technology that is to be required for BPT and BAT.

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* Treatment Train is defined as the combination of various unit processes and unit operations.

** Unit Process is defined as individual means of treatment in which the removal of contaminants is brought about by the addition of chemicals or biological activity.

*** Unit Operation is defined as individual means of treatment in which the application of physical forces predominate.

The use of this data as available from published sources to estimate required investments is described in detail in a later section.

### Water Quality Standards

The 1972 FWPCAA require that all effluents be treated to specified levels; secondary for public treatment works, BPT for non-publicly owned treatment works. In addition, if this level of treatment does not meet water quality standards as specified by the state, then additional treatment is required. For the two cases investigated in this study, one river is used as a water supply source and, therefore, requires high water quality, while the second flows into Lake Michigan and must insure lake standards.

### Inflation

Certainly one of the factors which will exert a major influence on total costs is the rate of inflation. Both the short term rate, defined as applying to the period of time up to the compliance date, as well as the long term rate which by definition extends from the compliance date onward, must be considered. The recent inflation rate as measured by Construction Cost and Building Cost Index as reported by Engineering News Record show an 8% annual rate of increase for the period February 1969 through February 1974. Forecasts for the next five years indicate that an average rate of 7 - 8% is likely, even though the initial annual rate will be 10 - 12%.

The total impact of the inflation rate on the results of the case studies was examined in sensitivity studies.

## Interest Rate on Borrowed Money

One significant cost component in most analysis is the interest paid on borrowed capital. While interest charges can be a significant fraction of total cost, they are of less impact in these studies for the following reason. The Federal government finances 75% of municipal construction, with this money coming primarily from tax revenue. Local governments pay for from 10% to 25% of total cost depending on the extent of state subsidies. Therefore, only a small fraction of total municipal costs are subject to interest charges.

Private sector costs, however, were assumed to be financed from bond sales. An interest rate of 7% as specified in EPA Development Documents for effluent treatment costs was used in this project. In addition, sensitivity studies with interest rates ranging from 5% to 12% were conducted.

## Demand Stimulated Price Increases

The 1972 Amendment requires that an estimated $20 billion be spent on water pollution control in the next few years. The peak expenditure is anticipated to occur in the years of 1976 and 1977 and to be approximately $6 billion per year. This expenditure is a significant increase above those expenditures which might have occurred in the absence of the 1972 FWPCAA, and can result in a decrease in other construction to compensate for environmental construction and an increase in the price of construction. This latter effect viewed as a temporary inflationary force, would result in a 1% increase in construction prices for 1976 and 1977 (Ref. 37)

In this study data as reported in Ref.37 was used to compute the price increase due to demand stimulation in the period 1976 through 1980. The consequences of a shift in compliance date from 1977, the resulting change in the distribution of expenditures and the resultant change in price increases was not considered in this study.

### Alternative Treatment Programs

As discussed earlier, the nature of the selected treatment or abatement program will very much affect total costs. The two case studies provide an opportunity to analyze the effect of many different alternatives including recycling of effluent, regionalization of treatment plants and the diversion and associated externalization of costs.

In order to make comparisons of the many treatment alternatives, in addition to specifying that an alternative satisfy water quality requirements along the river stretch, it was required that the system be closed. That is, all effluents had to be discharged to the basin upstream of the most downstream water segment. In other words, for comparison purposes a closed system is required. In actual design, this condition might not be required and to some extent this constraint is imposed for analytical reasons rather than water quality consideration.

### Alternative Industrial Process Technologies

Industrial pollution control costs may be substantially affected by the development of new industrial manufacturing processes. For example, in some areas where water is relatively scarce and costly, economics has dictated the development of manufacturing processes which recycle and re-use cooling water rather than discharge it.

Due to recent pollution control requirements, many industries have developed new processes and/or made major modifications to existing processes. In some cases it was possible to make the necessary process changes without excessive capital and/or product costs.

However, when these developments occur before the end of the economic life of the existing capital stock, then the present unamortized costs must be assumed by the industry as an addition to the new process/technology development costs.

The critical question in the case studies was whether either compliance date, 1977 or 1980, would result in addition process/technology development which could increase the total cost of compliance. For this project, MATHEMATICA examined the potential for technological innovation within a specific industry - Steel. It was found that new process/technologies would not have a significant impact for at least ten years; therefore, are not significant factors in the analysis of cost of compliance in 1977 or 1980.

The above discussions have each focused on a parameter and its impact on total investment. Parameters are discussed further in the case studies as they relate to the individual case study. The following section details cost estimating procedures utilized in this study.

## C. COST ESTIMATING

In performing the two case studies it was necessary to estimate the cost of all treatment required to achieve 1977 standards. The basic information required to estimate cost is the reduction in loads as specified by state water quality agencies. MATHEMATICA, under contract to the States of Indiana and Missouri, prepared load allocation studies for the two basins. The data contained in those reports (Refs. 10, 11) included flow data and percentage reduction in loads required to meet 1977 water quality standards. This information was available for all discharges on an outfall by outfall basis.

With the above information, it would have been possible to design a treatment system for each effluent or discharge and to have prepared a cost estimate for that system. Of necessity, the design would have specified all the unit processes required to achieve the proper level of treatment; however, utilizing this approach was far beyond the scope of this study. Therefore, MATHEMATICA developed an alternative approach which extended the cost estimating procedures utilized in the load allocation studies. The details of these procedures for municipal and then industrial treatment processes are described below:

### Municipal Sanitary Treatment Costs

The requirement to utilize advanced waste treatment (AWT) considerably complicates the problem of estimating costs. Cost relationships for secondary level biological treatment have been developed by many researchers (Ref.35); however, little information exists from which generic cost vs. level of treatment curves can be generated for AWT.

The approach utilized was to analyze the cost of treatment for a number of specific treatment plants of different size and removal efficiencies to develop a general cost curve for that train of processes that would be appropriate for the study area.

Basic secondary level treatment was assumed to remove 85% of influent BOD loads. Further increases in removal efficiency can be achieved by additional unit processes as shown in Figure 1. The processes required to achieve specified levels of removal are shown in Table 1. For example if 91% removal is required, then the treatment train would consist of conventional secondary treatment and rapid sand filtration (1a, 2); 94.3% removal requires a treatment train including secondary treatment and the following unit processes lime clarification (1b, 2, 3) and multi media filtration (3, 3a, 6,5,7c).

In order to develop an analytic approximation of costs, it was assumed that treatment costs could be expressed in the following functional form:

$$C = a_1 r^{a_2} Q^{a_3} \qquad (1)$$

where

$C$ = capital costs in 1974 dollars
$r$ = percent removal of pollutants
$Q$ = flow (cubic feet/sec.)
$a_i$ = specific coefficients to be determined. $i=1,2,3$

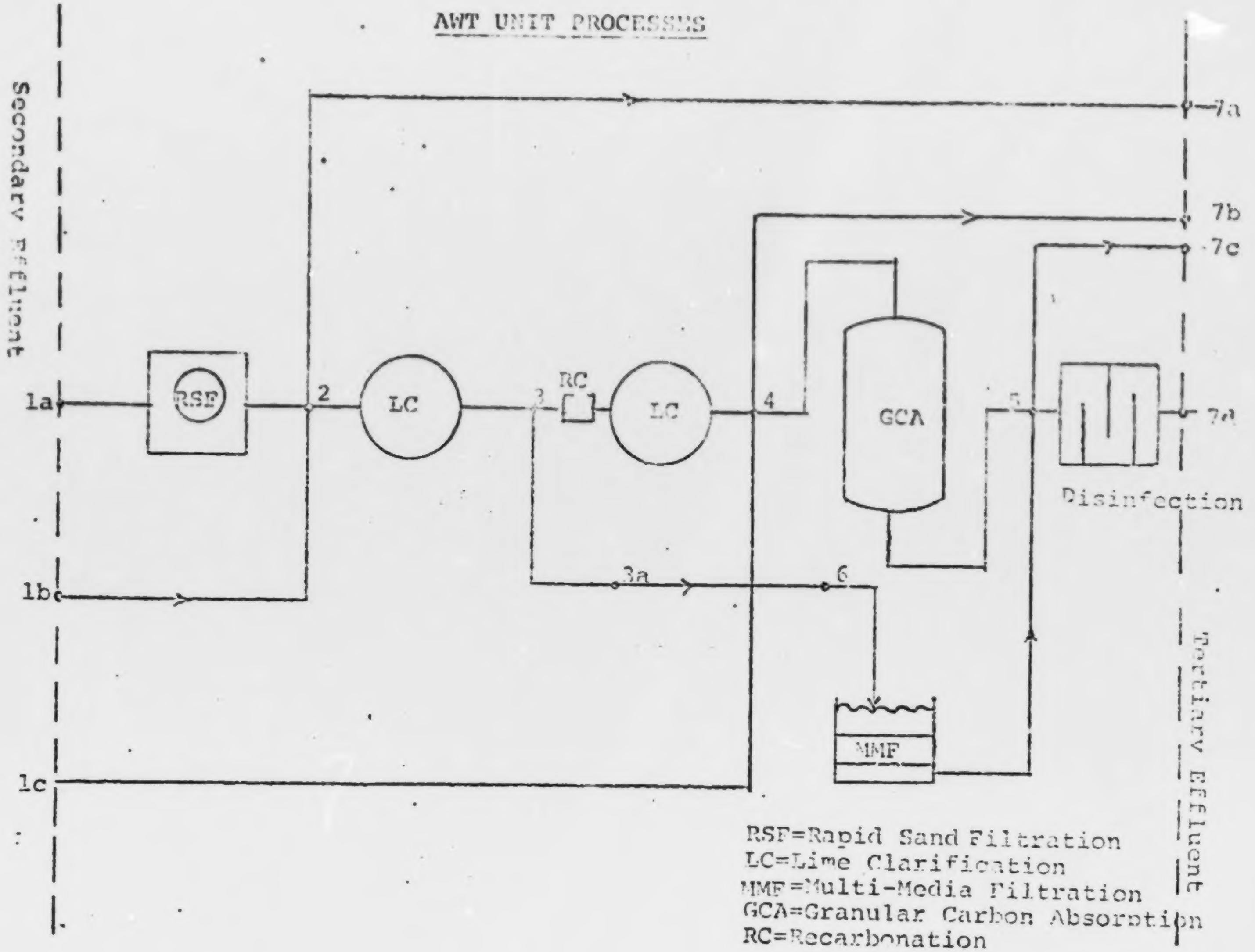
Using data for physical chemical treatment as reported by Smith and McMichael (Ref. 36) values for the coefficients were computed and are listed below:

$a_1 = 198{,}000$
$a_2 = 20.7$
$a_3 = 0.68$

Equation (1) was used in both case studies to generate cost estimates for physical chemical treatment.

FIGURE 1

AWT UNIT PROCESSES



**Reference:** "Cost and Performance Estimates for Tertiary Wastewater Treating Processes," by Robert Smith and Walter F. McMichael. Ref. 36)

TABLE 1

## PHYSICAL CHEMICAL TREATMENT TRAIN EFFICIENCIES

| PROCESSES | FLOW TRAIN | LEVEL OF REMOVAL (%) |
|---|---|---|
| RAPID SAND FILTRATION | 1a, 2, 7a | 91.0 |
| LIME CLARIFICATION | 1b, 2, 3, 3a, 4, 7b | 93.5 |
| LIME CLARIFICATION & MULTI-MEDIA FILTRATION | 1b,2,3,3a,6,5,7c | 94.3 |
| GRANULAR CARBON ABSORPTION | 1c, 4, 5, 7c | 97.7 |
| LIME CLARIFICATION & GRANULAR CARBON ABSORPTION | 1b,2,3,4,5,7c | 98.8 |

Source: "Cost and Performance Estimates for Tertiary Wastewaterreating Processes," by Robert Smith and Walter F. McMichael, (Ref. 36)

However, physical chemical processes would not always be utilized for all waste treatment plants. In engineering practice, two stage activated sludge is a substitute for physical chemical treatment and would be used in many instances. Therefore, it was necessary to develop an estimate of the cost of two stage activated sludge treatment. Cost estimates generated using equation (1) were compared to actual design cost estimates for two stage activated sludge plants in Indiana. It was found that equation (1) although calibrated for physical chemical processes was also a good estimator of costs for a two stage activated sludge treatment train.

Two stage activated sludge was included as an alternative treatment train and costs were estimated using equation (1). The actual hierarchy of processes used to estimate treatment costs are shown in Table 2. This data was used only to estimate costs for AWT. Since secondary level treatment is required of all publicly owned plants, the above data is sufficient to minimize treatment costs for load allocation studies.

It should be noted that of the processes shown in Table 2, only two stage activated sludge provides ammonia removal. Ammonia can be removed at lower levels of BOD removal with the addition of Lime Clarification plus Air Stripping; however, total costs equal the costs of two stage activated sludge. Furthermore, air stripping is severly limited during extremely cold periods. Therefore, ammonia removal is analyzed separately with the analysis further complicated by the fact that both BOD and ammonia affect DO. It is possible to trade off BOD treatment for ammonia treatment and vice versa. That is, as ammonia loads decrease, additional BOD loads can be assimilated by the water body within the constraint of some specified DO goal. Reference 11 provides a description of how this tradeoff affects wasteload allocations for the Meramec.

TABLE 2

PHYSICAL-CHEMICAL & BIOLOGICAL TREATMENT TRAIN EFFICIENCIES

| PROCESSES* | REMOVAL |
|---|---|
| Conventional Activated Sludge | Up to 85% |
| Facilities for additional detention time for Single Stage Activated Sludge | 85 - 90 % |
| Filtration, Lime Clarification or combination of these two processes | 90 - 94.5% |
| Two Stage Activated Sludge | 94.5 - 97% |
| Granular Carbon Absorption | 97 - 98% |
| Lime Clarification and Granular Carbon Absorption | 98 - 99% |

* Each process is assumed to be added to conventional treatment.

Source: MATHEMATICA, Inc.

In order to estimate municipal treatment costs for the Calumet discharges, actual anticipated construction costs as available for Gary STP were used (Reference 22). These costs were modified to estimate costs for the remaining municipal plants.

The above methodology is suitable for use in estimating the costs of sanitary/municipal waste treatment because of the homogeneity of the plant input. Unfortunately, industrial discharges are not homogenous and alternative estimating techniques are required. These techniques are discussed below.

## Industrial Treatment

The approach utilized above for estimating the costs of municipal sanitary waste treatment was extended to estimate the cost of industrial treatment. The basic approach was to apply known transformations to cost data for a given plant or treatment train operating under specified conditions to estimate the cost of treatment under differing conditions.

While it was possible to use a basic set of unit processes, e.g. activated sludge, lime clarification, etc., as basic building blocks for the treatment of homogenous sanitary wastes, in general, the heterogeneity of industrial discharges does not allow this option. This is true even within an industry such as steel. Instead, it is necessary to determine the series of unit processes or treatment train to be used for the treatment of each discharge. The engineering solution to this problem is to "design" a treatment train for each discharge to then estimate the cost of that train. To do this for each discharge was beyond the scope of this study. A more analytic alternative approach was taken.

EPA has published a series of Development Documents for Effluent Guidelines for various industrial categories*. These documents define BPT and BAT and provide performance specifications and cost estimates of treatment for the average size industrial plant. Unfortunately, the actual discharges were not "average" size, and in addition, many required treatment at removal efficiencies which exceeded BPT.

Actual treatment costs for both municipal and industrial treatment processes is a function of the process efficiency (the fraction of pollutants removed) and size (the flow). Therefore, it was necessary to modify these "average" costs to reflect differences in flow and treatment efficiency. Each of these factors is discussed below.

For each discharge the quantity of flow, the existing loads and required load reductions are all specified in the load allocation studies (References 10,11). Using these references it is also possible to determine the industry category for each discharge.

## Efficiency

The relationship between the level of treatment (percentage load removal) and cost is difficult to quantify, since unit processes are each operable over a range of efficiencies. To increase unit process, a second unit process is added in series to the original process to form a treatment train. In some cases this second process, if it has a high efficiency, can replace the first process. Several unit processes can be added in series to increase the overall train efficiency. However, the cost characteristics of such trains is shown in Figure 2. Once a minimal point is reached, the cost of increased efficiency tends to increase rapidly. This marginal cost curve results in the relationship shown in Figure 3. These relationships are characteristics of a broad range of waste treatment processes (Ref. 40) and represent the best estimate possible within the scope of this study. The relationships used for this study are based on Ref. 40.

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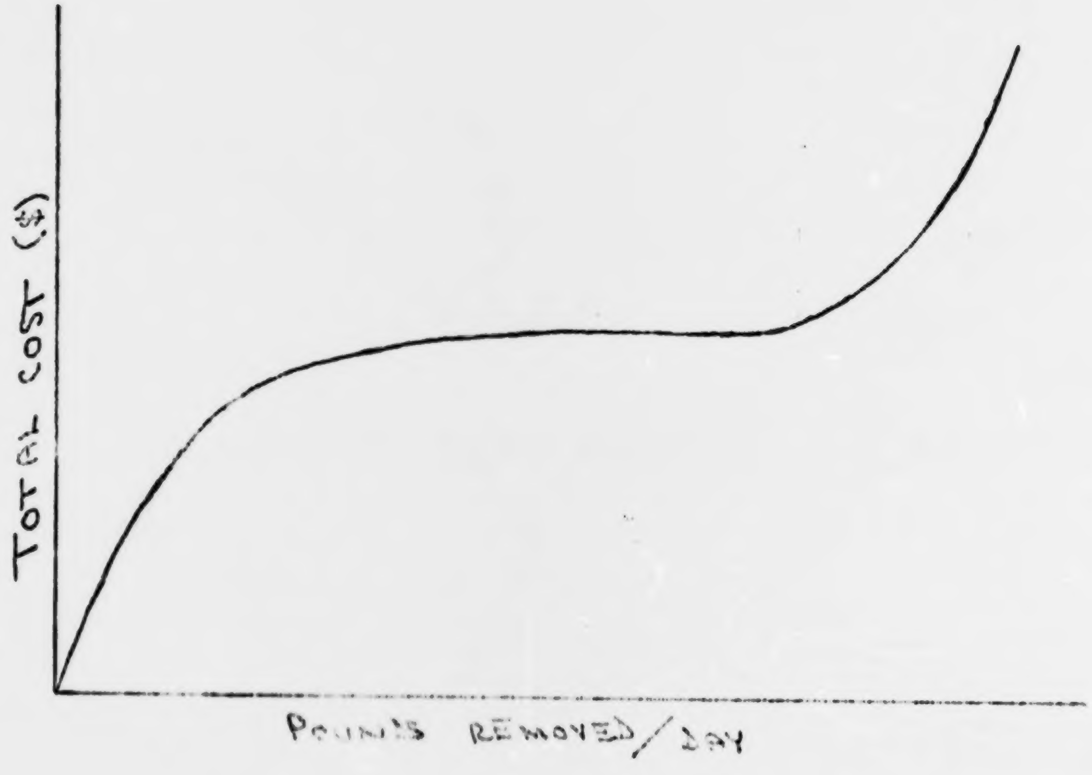
* Each industry group is described in detail and the different processes with the industry are grouped into categories according to logical industrial operations. For example, steel-making categories include coke manufacturing, blast furnace operation, coking and others. For each category water cycles are described, and all loads contributed by that process are identified and quantified. Various alternatives or options within a category are described. For example, blast furnace, basic oxygen furnace, open hearth and electric arc furnaces are all alternatives of steel making processes. Finally, different alternatives within a process are described. For example, wet, dry and semi-wet scrubbers are shown as different options for controlling particulate emissions. For each feasible combination of processes within a category, water requirements and loads are described, BTP treatment is defined, effluent characteristics are stated and capital and O&M costs are listed.

Using the general shape shown in Figure 3 and the data available in the Development Documents, it is possible to generate a family of curves for each category and process within an industry. These curves plot cost vs. removal efficiency for the various pollutants found in the process discharge. Any single train of processes specified as BPT for a specific category will operate at different removal efficiencies for different substances. That is, a process costing $C_1$ dollars will remove $P_i$ of substance "i", & $P_j$ of substance "j" where $P_i$ does not equal $P_j$. For example, for blast furnaces, BPT treatment reduces ammonia loads by 60%, phenols by 87% and cyanides by 76%, at a cost of approximately $1.5 million (Ref. 45). Constraining the curve shown in Figure 3 to fit through the point defined by removal efficiency for each pollutant and treatment train cost results in a family of curves for any single process train. Using the above data it is possible to generate the family of curves shown in Figure 4.

## FIGURE 2

## COST VS. REMOVAL EFFICIENCY

## TYPICAL RELATIONSHIP



# FIGURE 3

## MARGINAL COSTS OF LOAD REDUCTION

## TYPICAL RELATIONSHIP

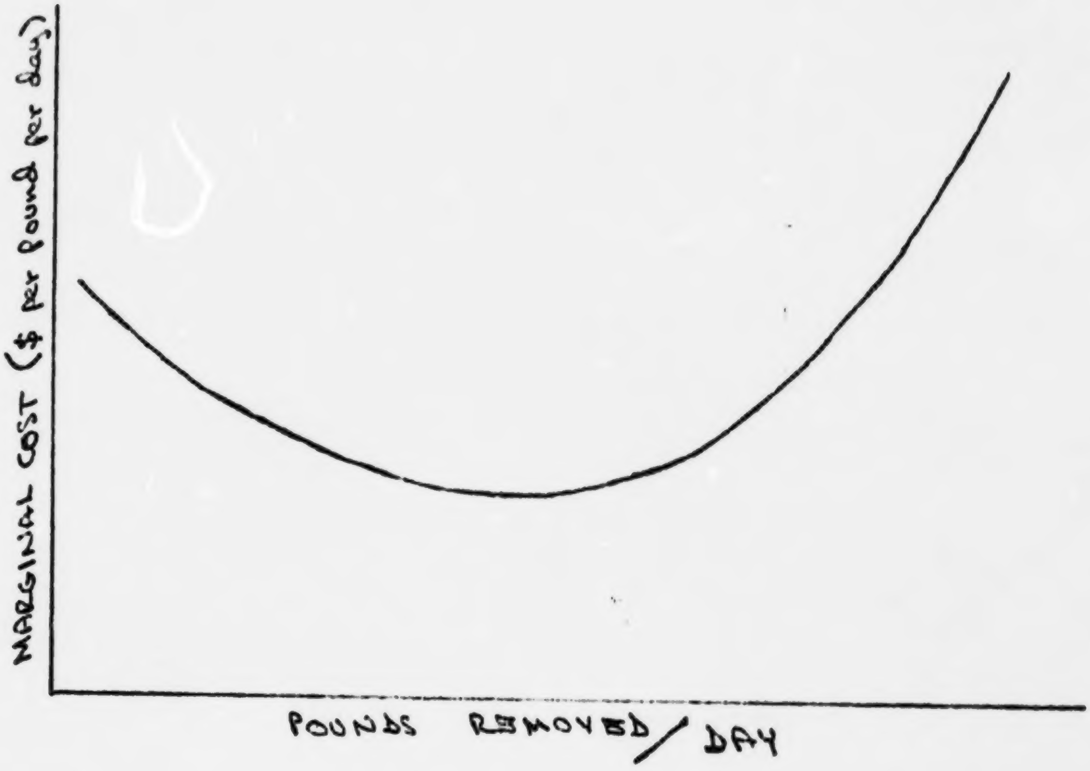
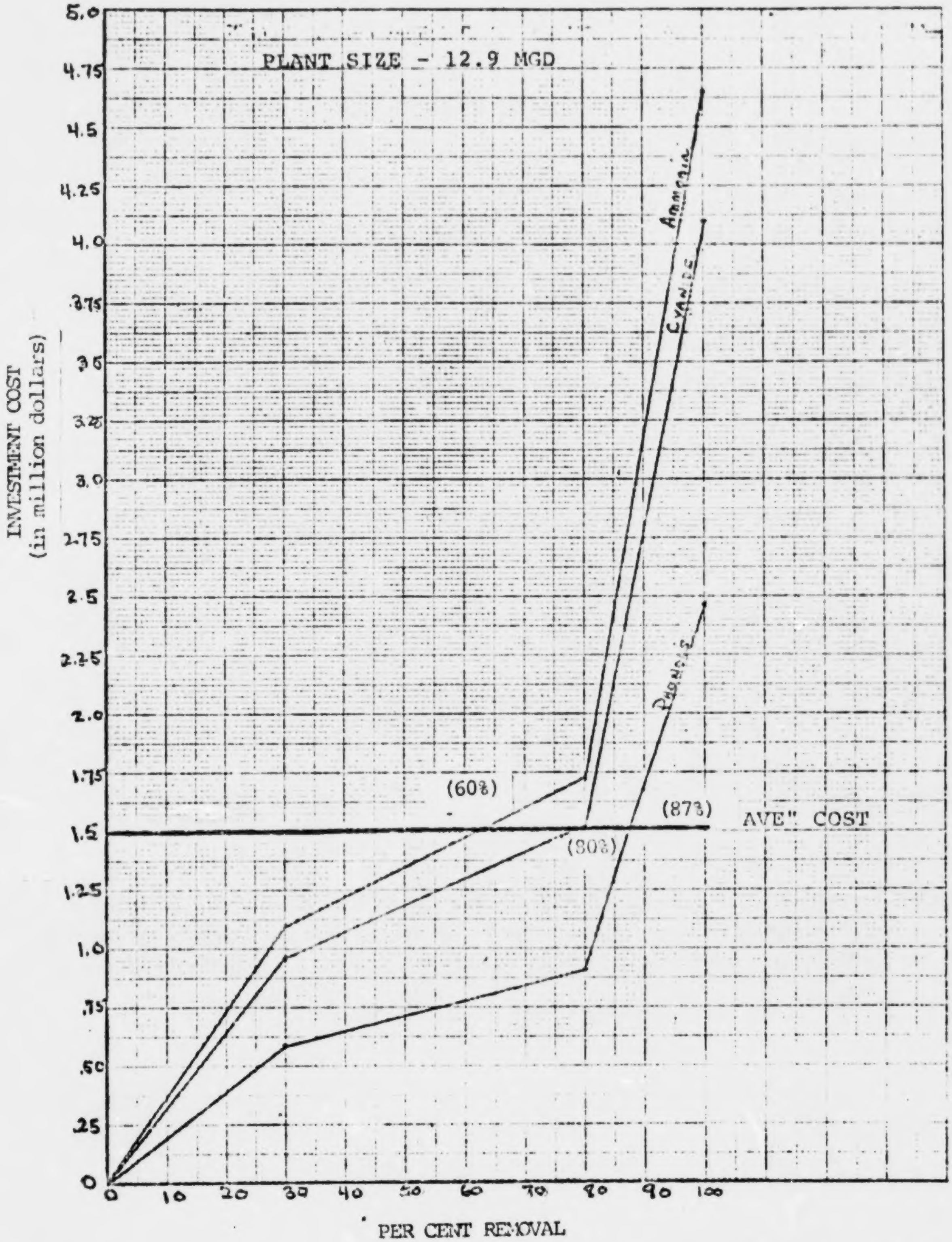


FIGURE 4

INVESTMENT COST VS. PERCENT REMOVAL FOR BLAST FURNACES



ce: U. S. Environmental Protection Agency, Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Steelmaking Segment of the Iron and Steel Manufacturing Point Source Category, EPA 440/1-73/024, Figure 4 represents investment costs as a function of removal efficiency for three different polluting substances. The process used to generate Figure 4, is most cost effective in removing phenols, with ammonia and cyanide removal being approximately twice as costly.

### Flow

The above transformations all assume constant flows. There is considerable research available which quantifies the relationship between cost and flow (Ref. 34) and equation (2) best expresses cost as a function of size:

$$C = AQ^m \tag{2}$$

where:

$C$ = cost
$A$ = a constant
$Q$ = a measure of flow
$m$ = a coefficient ranging from 0 to 1

The value of A is determined by the particular treatment train, and units of flow. The parameter "m" varies between zero and one and is a measure of the economies of scale inherent in the process. If m equals one, then there are no economies of scale, while if m is zero then the cost would be constant. In this study a value of 0.68 as derived in Reference 29 was used for m.

However, if cost and size are known for a specific plant, it is not necessary to calculate "A". Instead, it is possible to compute treatment cost directly from known data. Using cost and size data specified in the EPA Development Documents it is possible to calibrate equation (3) which is derived from equation (2).

(3) $\text{Cost}_D = \text{Cost}_{AVE} \left(\frac{Q_D}{Q_{AVE}}\right)^m$

where

$\text{Cost}_D$ = cost of treating discharge "D"
$Q_D$ = quantity of flow discharge "D"
$Q_{AVE}$ = average flow as specified in Development Document
$\text{Cost}_{AVE}$ = average treatment cost as specified in Development Document

Equation (3) is applied to the costs determined from Figure 4 to estimate discharge treatment costs. A more detailed discussion of the application of the methodology to the Calumet is provided below in an example.

## D. AN EXAMPLE

The cost estimate for a single discharge is derived from EPA cost estimates through two transformations as described below for Inland 4E-1. Inland 4E-1 is an outfall which includes process water, contact and noncontact cooling water from blast furnaces and noncontact cooling water from a coke plant. The discharge has an average treatable flow of 35.8 MGD from the blast furnaces and based on allocation loads removal efficiencies of 28%, 50% and 98% are required for ammonia, phenols and cyanides respectively.

For an "average" size steel mill as defined in the EPA Development Documents, a similar blas furnace discharge has an average flow of 12.9 MGD with waste treatment removal efficiencies of 60%, 87% and 76% respectively for ammonia, phenols and cyanides respectively. The cost of the blast furnace discharge treatment process was estimated at $1,477,000 (Ref.45). As stated previously, this data was used to generate Figure 4.

It is now possible to estimate the cost of treatment for 4E-1. The first step is to pick off costs for treatment for each removal efficiency required by the load allocation. For 4E-1, the loads and percent reductions for ammonia, phenols, and cyanides are 1000, 17.4 and 934 pounds per day and 28%, 50%, and 98% respectively. Thus the treatment costs associated with the required levels of removal as found in Figure 4 are $1,050,000 for ammonia, $680,000 for phenols and $3,780,000 for cyanides. The maximum cost estimate is then used and the significance of the estimate is that "if 4E-1 had the average flow of 12.9 MGD," treatment costs would be $3.78 million.

The second step in estimating 4E-1 costs is to determine the cost for the above treatment level at a flow of 35.8 MGD, the actual flow for 4E-1. Substituting in equation (3),

$$\begin{aligned} \text{COST}_{4E-1} &= \text{COST}_{AVE} \left(\frac{Q_{4E-1}}{Q_{AVE}}\right)^{0.68} \\ &= \$3,780,000 \left(\frac{35.8}{12.9}\right)^{0.68} \\ &= \$7,545,000 \end{aligned}$$

It must be emphasized that the cost estimating process just outlined is an approximation procedure necessitated by the lack of other data. However, it provides an estimate of treatment costs as available short of designing the treatment process for each and every discharge stream.

## E. CALUMET COST ESTIMATION

For the industrial discharges, the great bulk of treatable flows originate from three major steel plants in the Calumet Basin.

The costs for the Calumet Steel plants are calculated using the EPA BPT and BAT costs for the coke making, iron production, and steel making segments of the industry. Each industrial outlet is categorized to fit a particular EPA process for which costs are available. Due to water quality limitations, cost of achieving 1977 standards for the Calument steel plants includes costs for implementing Best Available Treatment (BAT) for phenol effluents.

For the other industries in the Calumet Basin, only ammonia and phosphorus removals were significant and the treatment cost estimates were derived from other information sources.

Information Sources for Costs and Load Allocations

The basic references used to estimate municipal and industrial treatment costs are shown in Table 3.

Load allocations, necessary to meet water quality standards for all point source discharges into the Grand Calumet Basin, are taken from three sources

(1) "Summary Waste Load Allocations Grand Calumet River and Indiana Harbor Canal", Staff Memo to Indiana State Pollution Control Board from S. L. Moore, 5/21/74 (Ref. 28)

(2) "Load Allocation Study of the Grand Calumet River and Indiana Harbor Ship Canal" Combinatorics, Inc., Lafayette, Indiana, January, 1974 (Ref 10)

(3) "Load Allocation for Grand Calumet River and Indiana Harbor Ship Canal - Best Practical Treatment Limits - Combinatorics Memo, Lafayette, Indiana, 1973. (Ref 12)

## TABLE 3

## COST INFORMATION SOURCES

Reproduced from best available copy.

| CATEGORY | REFERENCE IDENTIFICATION |
|---|---|
| BPT for Steel Industry | EPA Development Document for Effluent Guidelines for Steel Making, February, 1974. (Ref. 45) |
| BAT for Industrial Phenol Removal | Cost and Performance Estimate for Tertiary Wastewater Treatment Processes by Robert Smith and Walter McMichael (Ref. 36) |
| BPT for Industrial Ammonia Removal | Wastewater Ammonia Removal by Ion Exchange - Battelle Report, 1971 (Ref. 4) |
| Industrial Phosphorus Removal | Ford, Bacon & Davis, private correspondence. (Ref. 20) |
| Municipal Advanced Waste Treatment for the Gary Sewage Treatment Plant | Advanced Wastewater Treatment Facilities for Sanitary District of Gary, Havens & Emerson Ltd., Consulting Environmental Engineers (Ref. 22) |
| Municipal Advanced Waste Treatment for the East Chicago and Hammond Sewage Treatment Plants | Same as above |

## Cost Estimation

The Calumet steel mill discharge categories were matched with the steel making process categories found in the EPA Development Documents as shown in Table 4. The dashed lines in the right column indicate that there is no Calumet corresponding to the opposite EPA process category.

The electric arc and BOF processes with wet air pollution control equipment are much more frequently used than their semi-wet counterparts. Therefore, whenever BOF and electric arc processes are encountered in the Calumet Basin, they are matched with wet air pollution control categories.

The EPA Development Document gives costs only for the steel making processes up through steel making, and continous casting and excludes all hot and cold finishing processes, and do not include hot forming, cold rolling, pickling, plating, coating and galvanizing operations. The Development Document for these steel finishing processes is not yet available. Of these, the hot forming and cold rolling processes have effluents similar to those which result from the continuous casting process. Consequently, whenever a discharge for these two processes is encountered, it is matched with the continuous casting category. No corresponding category was found for the remaining categories. This is of little consequence in the Calumet since the load allocations do not require treatment of any effluents from these processes.

## TABLE 4

## EPA STEELMAKING PROCESS MATCHED WITH CORRESPONDING CALUMET STEELMAKING CATEGORY

| EPA STEELMAKING CATEGORY | CALUMENT STEELMAKING CATEGORIES |
|---|---|
| BY PRODUCT COKE | COKE MANUFACTURING |
| BEE HIVE COKE | - |
| SINTERING | SINTERING |
| BLAST FURNACE (IRON) | BLAST FURNACE (IRON PRODUCTION) |
| BLAST FURNACE (FeMn) | - |
| BASIC OXYGEN FURNACE (BOF)<br>(semi-set air pollution control) | - |
| BASIC OXYGEN FURNACE (BOF)<br>(wet air pollution control) | BASIC OXYGEN FURNACE<br>(steel making) |
| OPEN HEARTH | OPEN HEARTH (STEEL MAKING) |
| ELECTRIC ARC FURNACE<br>(semi-set air pollution control) | - |
| ELECTRIC ARC FURNACE<br>(wet air pollution control) | ELECTRIC ARC FURNACE<br>(steel making) |
| VACUUM DEGASSING | - |
| CONTINUOUS CASTING | CONTINUOUS CASTING, HOT FORMING, COLD ROLLING |

There are a few other discharges including power plants which do not fall into the categories listed in the table; however, these discharges required no treatment under the state load allocations.

There are some discharges which consist of effluents from two or more processes. In this situation, the loads coming from the outlet are allocated to each process category in the ratio of the total effluent flow coming from each process.

## Load Allocations

The loads established by the State of Indiana are used for this study and are defined as aggregate loads for each company and municipality. Individual discharge loads, both existing and allocated are based on Ref. 10 . When there is any inconsistency in load data, the state loads are given preference.

## Treatable Flows

To obtain reasonable estimates of the costs, it is not necessary to always treat the total flow coming from an individual outlet discharge. Thus the flow for each outlet is analyzed to determine what fraction of the flow requires treatment.

The cost estimates developed by the above process are further adjusted to reflect the impact of inflation, price increases due to stimulated demand and in some cases phenol removal. Because phenol removal consistently approached BAT levels, each discharge was examined to determine if an additional adjustment to the cost estimate reflecting the cost of carbon absorption was required. In general the processes described above would generate costs which are slightly higher than costs developed from design data. The effect of this type of a bias was analyzed in sensitivity studies and a slight bias does not effect the results of the case studies.

## F. LIMITATIONS AND ASSUMPTIONS OF THE COSTING PROCEDURES

The following assumptions were required in order to estimate treatment costs.

### Treatable Flows

It was not necessary to treat the total flow from an outlet where large portions of an effluent were non-contact cooling water which normally contains no process loads. Therefore, non-contact cooling water flows were subtracted from the total flow to obtain the treatable flow. In those cases where the cooling water was significantly polluted in the cooling process, the non-contact water was included in the treatable flow category.

There were other miscellaneous flows, such as power plant effluents where discharge by discharge judgements were made as to whether or not to include the discharge in the treatable category.

### Problem Constituents Not Treated

There were two constituents not treated which have a severe impact on the Calumet Basin and Lake Michigan. These were sulfates and chlorides. However, for these substances the costs for treatment removal were high and brine disposal was a significant environmental problem. At present, the State of Indiana does not require treatment for these constituents.

## SECTION IV
## CASE STUDY 1 - THE MERAMEC

### A. BASIN DESCRIPTION

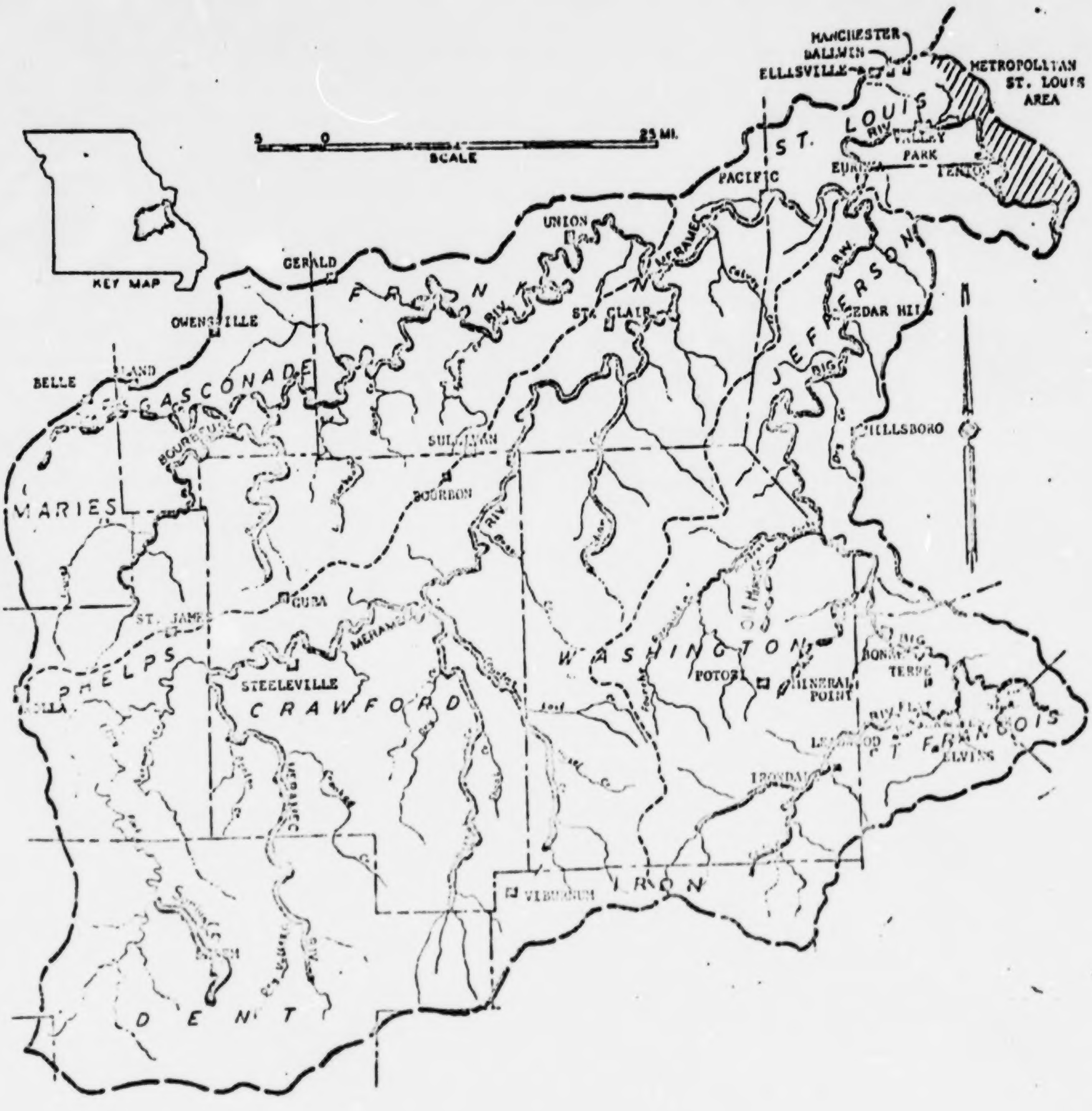
The Meramec River Basin is located southwest of St. Louis, Missouri, with the Meramec flowing into the Mississippi just south of the city (See Figure 5 ). It drains approximately 4,000 sq. miles of eastern central Missouri, with the upper reaches meandering through a very picturesque and rural area where agricultural activities have the most significant impact on the stream.

Starting at river mile 23, where it enters the outer suburban area of St. Louis, the river is referred to as the Lower Meramec River. The Meramec flows through the outer suburbs of St. Louis before flowing into the Mississippi. In this last section the river slows as the bottom slope decreases varying between 0.2 ft/mile to 0.5 ft/mile. The average flow is approximately 3,000 cfs with average velocity varying from 0.8 ft/sec. to 1.4 ft/sec. At a flow of 1,000 cfs the river depth is generally 10 to 12 feet with a few reaches dropping off to twenty-five or thirty-five feet. These deeper sections are a result of excavation and Mississippi River backwater.

The lower basin area is currently experiencing rapid growth as people migrate from St. Louis. During the period from 1960 to 1970 while the populations of St. Louis and East St. Louis, Illinois fell 17%, the population in the Lower Meramec drainage area increased 100% from 66,879 to 134,646. This high rate of growth is expected to continue and by 1980, the population is expected to increase by from 70% to 100%. This population increase, coupled with efforts to eliminate septic tank operations, will greatly increase wastewater loadings, which are estimated to increase by an amount ranging from between 130% to 154% of the existing flow.

FIGURE 5

# UPPER MISSISSIPPI RIVER BASIN
# MERAMEC RIVER BASIN



At present, most of the existing wastewater is treated in countless small wastewater treatment facilities, which discharge to the many creeks which are tributaries to the mainstem (Figure 6 ). At best, these facilities provide marginal secondary treatment; at worst, primary (Table 5 ).

All major industrial discharge are to the mainstem, except for Western Litho Plate and Supply Company, which discharges to the Grand Glaize Creek. There are twenty direct discharges to the mainstem. Several of these discharges, including Chrysler's storm sewer and Union Electric's refuse bottom ash discharge, are intermittent. While most discharges are industrial, many of these industries discharge only sanitary wastewater. Chrysler Corporation, Ashland Chemical Company, Absorbent Cotton Company, Inland Container Corporation, Winter Brothers Materials Company, Fred Weber and Union Electric's Meramec River Power Plant all discharge industrial wastewater to the Lower Meramec. The first four discharge highly concentrated organic loads, with Absorbent Cotton's maximum discharge of 6,100 lbs/day of $BOD_5$ by far the most significant. Other maximum $BOD_5$ loads include Chrysler (1,540 lbs/day), Ashland Chemical (140 lbs/day), and Inland Container (60 lbs/day). In addition, Chrysler, Ashland Chemical and Absorbent Cotton are major dischargers of phenols, with Winter Brothers and Fred Weber's gravel mining operations discharging minor organic loads. The power plant also generates a minor organic load but presents no thermal problem at present.

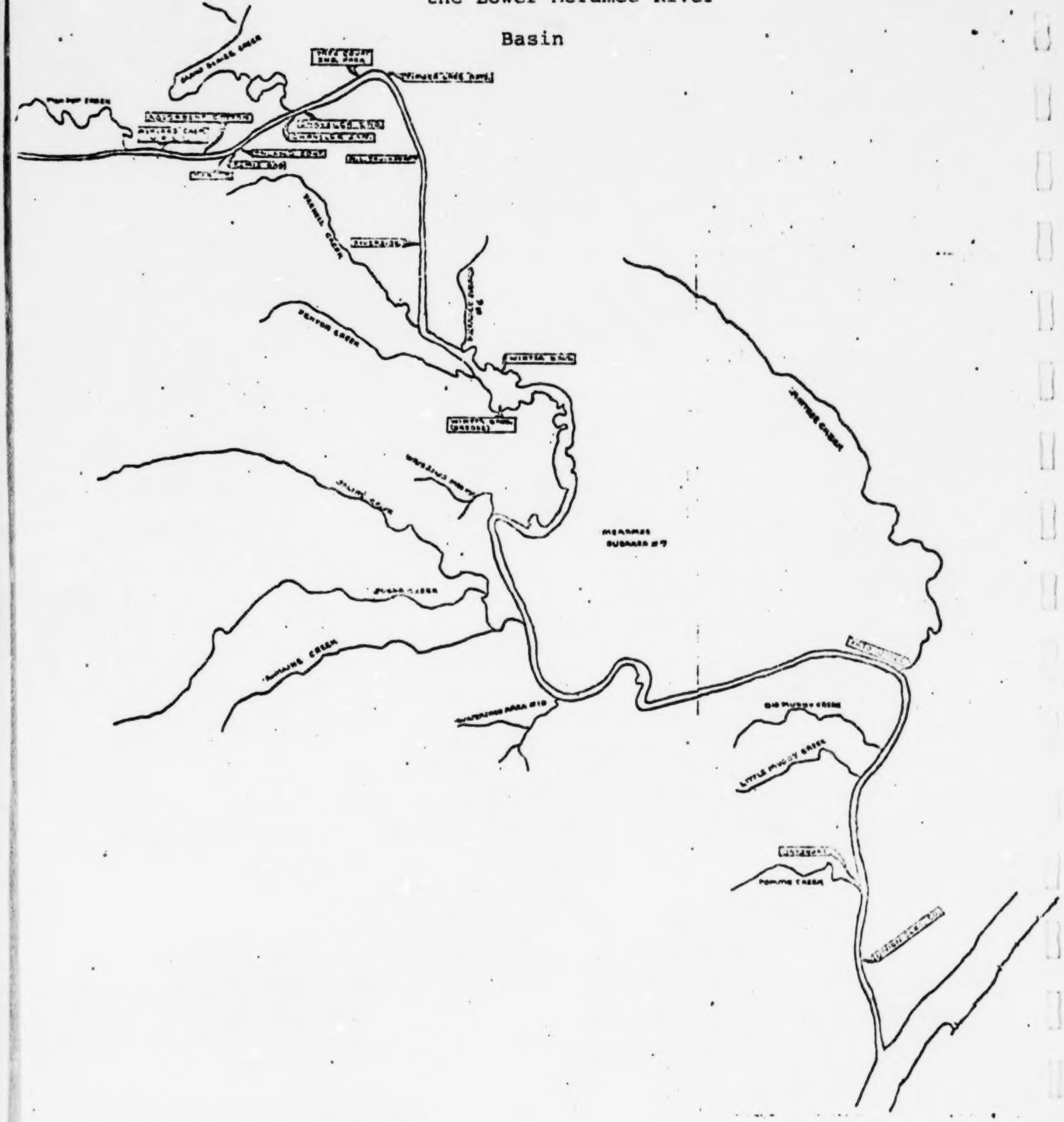
A summary description of the various discharges to the Meramec is given in Table 6 . The creeks are treated as direct discharges to the Meramec and the flow listed is the total discharged flow to the creek from various facilities.

Figure 6

Point Source Discharge to

the Lower Meramec River

Basin



Source: MATHEMATICA, Inc.

TABLE 5

WASTE SOURCE INVENTORIES (MAXIMUM FOR CREEKS)

| State: Missouri | | Basin: Meramec | | | Segment: RM 22.5 to 0.0 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Waste Sources | Location (River Mile) | Type of Sample | Flow (cfs) | $BOD_5$ (lbs/day) | $NH_3$-N (lbs/day) | $NO_2$ & $NO_3$ (lbs/day) | COD (lbs/day) | Phosphorus (lbs/day) | Phenols (lbs/day) |
| Fishpot Creek | 22.4 | G | 70.41 | 3,674.3 | 2,840.1 | 606.1 | 20,455.0 | 2,765.2 | .215<br>(5.00) |
| Grand Glaize Creek | 20.33 | G | 9.80 | 2,320.1 | 142.3 | 296.4<br>(20.4) | 5,536.7 | 192.1<br>(20.4)* | .369 |
| Yarnell Creek | 16.11 | G | 14.00 | 979.3 | 91.2 | 105.4 | 6,930.2 | 278.7 | DNA |
| Fenton Creek | 15.20 | G | 67.60 | 3,637.3 | 250.0 | 181.8 | 17,095.4 | 418.3 | DNA |
| Saline Creek | 10.42 | G | 9.91 | 218.6 | 13.9 | 17.4 | 1,439.7 | 30.9 | DNA |
| Mattese Creek | 4.76 | G | 78.60 | 13,956.3 | 1,818.5 | 296.0 | 42.291.9 | 1,607.1 | DNA |
| Big Muddy | 3.72 | G | 38.10 | 5,535.1 | 1,250.5 | 123.0 | 18,655.2 | 332.8 | DNA |
| Little Muddy | 3.32 | G | .51 | 57.6 | 10.2<br>(.70) | 7.9<br>(.70) | 327.1<br>(.80) | 17.6<br>(.80) | DNA |
| Total Creek Load | | | | 30,378.6 | 6,416.7 | 1,634.0 | 92,276.2 | 5,642.7 | .584 |

*Values given in () are flows in cfs at which this particular load was measured. This is done where the flow differes from the one given in the flow column.

DNA - Data Not Available    G - Grab Sample

Source: Combinatorics, Inc., (A Subsidiary of MATHEMATICA, Inc.), Load Allocation Study of the Lower Meramec River Basin, Lafayette, Indiana, June, 1974. (Ref. 11)

TABLE 5 (continued)

WASTE SOURCE INVENTORIES (AVERAGE FOR CREEKS)

State: Missouri    Basin: Meramec    Segment: RM 22.5 to 0.0

| Waste Sources | Location (River Mile) | Type of Sample | Flow (cfs) | $BOD_5$ (lbs/day) | $NH_3$-N (lbs/day) | $NO_2$ & $NO_3$ (lbs/day) | COD (lbs/day) | Phosphorus (lbs/day) | Phenols (lbs/day) |
|---|---|---|---|---|---|---|---|---|---|
| Fishpot | 22.40 | G | 3.0 | 102.5 | 135.7 | 35.8 | 674.7 | 139.4 | .031 |
| Grand Glaize | 20.38 | G | 9.3 | 1,371.1 | 63.5 | 128.6 | 2,707.2 | 97.6 | .090 |
| Yarnell | 16.11 | G | .42 | 12.0 | 1.7 | 4.9 | 88.1 | 6.6 | NDA |
| Fenton | 15.20 | G | 1.1 | 113.0 | 45.8 | 2.7 | 413.1 | 42.0 | NDA |
| Saline | 10.42 | G | 4.35 | 58.73 | 4.5 | 35.6 | 430.6 | 8.4 | NDA |
| Mattese | 4.76 | G | 4.03 | 673.29 | 183.9 | 13.9 | 1,949.4 | 138.5 | NDA |
| Big Muddy | 3.72 | G | .73 | 67.9 | 30.3 | .90 | 246.7 | 22.4 | NDA |
| Little Muddy | 3.32 | G | .55 | 53.6 | 7.0 | 5.6 | 168.7 | 11.0 | NDA |
| Total Creek Load | | | | 2,542.1 | 472.5 | 228.0 | 6,678.5 | 446.0 | .121 |

NDA - No Data Available    G - Grab Sample

## MERAMEC DISCHARGERS

| DISCHARGER (RIVER MILE) | TYPE | TREATABLE PROBLEM POLLUTANTS | EXISTING AVERAGE FLOWS (MGD) | 1980 PROJECTED AVERAGE FLOWS (MGD) |
|---|---|---|---|---|
| FISHPOT CREEK (22.40) | SANITARY | $BOD_5$, $NH_3$-N | 2.50 | 2.70-3.15 |
| ASHLAND CHEMICAL (21.90) | ALKYD AND POLYESTER RESIN PRODUCTION | PHENOLS | .50 | .50 |
| ABSORBENT COTTON (21.52) | MANUFACTURE OF SURGICAL DRESSINGS | $BOD_5$, PHENOLS | 1.40 | 1.40 |
| MARITZ (21.24) | SANITARY | $BOD_5$, $NH_3$-N | .04 | .04 |
| BEMIS BAG (21.08) | SANITARY | $BOD_5$, $NH_3$-N | .02 | .02 |
| INLAND CONTAINER (20.98) | PRINTING PRESS AND STARCH ADHESIVE WASHUP WATER | $BOD_5$ | .04 | .04 |
| GRAND GLAIZE CREEK (20.38) | 2.80 SANITARY<br>0.50 LITHO PLATE SUPPLY | $BOD_5$, $NH_3$-N | 3.30 | 4.68-6.80 |
| CHRYSLER STORM (20.36) | RUNOFF | NONE | INTERMITTENT | INTERMITTENT |
| CHRYSLER (20.36) | SANITARY | $BOD_5$, $NH_3$-N | .20 | .20 |
| CHRYSLER (20.13) | MOTOR VEHICLE ASSEMBLY | $BOD_5$, PHENOLS | .50 | .50 |
| TREE COURT INDUSTRIAL PARK (19.40) | SANITARY | $BOD_5$, $NH_3$-N | .04 | .04 |
| TIMBER LAKE APTS. (19.18) | SANITARY | $BOD_5$, $NH_3$-N | .04 | .04 |
| ST. LOUIS TRUCKPORT (18.05) | SANITARY | $BOD_5$, $NH_3$-N | * | * |
| RIVERSIDE (17.10) | SANITARY | $BOD_5$, $NH_3$-N | .08 | .08 |
| YARNELL CREEK (16.11) | SANITARY | $BOD_5$, $NH_3$-N | .30 | .50-.69 |
| SUBAREA #6 (15.48) | SANITARY | $BOD_5$, $NH_3$-N | * | .23-.30 |

* Insignificant Discharge

Source: Combinatorics, Inc., (A Subsidiary of MATHEMATICA, Inc.), Load Allocation Study of the Lower Meramec River Basin, Lafayette, Indiana, June. 1974. (Ref. 11)

TABLE 6 CONTINUED

| DISCHARGER (RIVER MILE) | TYPE | TREATABLE PROBLEM POLLUTANTS | EXISTING AVERAGE FLOWS (MGD) | 1980 PROJECTED AVERAGE FLOWS (MGD) |
|---|---|---|---|---|
| FENTON (15.20) | SANITARY | $BOD_5$, $NH_3$-N | 0.35 | .56-1.07 |
| WINTER BROS. (15.00) | GRAVEL MINING OPERATION | NONE | 1.24 | 1.24 |
| WINTER BROS. (DREDGE) (15.00) | DREDGE OPERATION | NONE | 1.72 | 1.72 |
| SUBAREA #7 (13.14) | SANITARY | $BOD_5$, $NH_3$-N | * | .33-.50 |
| WATERSHED AREA #32 (12.50) | SANITARY | $BOD_5$, $NH_3$-N | .10 | .15-.20 |
| SALINE CREEK (10.42) | SANITARY | $BOD_5$, $NH_3$-N | .60 | .80-1.00 |
| WATERSHED AREA #10 (9.87) | SANITARY | $BOD_5$, $NH_3$-N | .07 | .10-.13 |
| FRED WEBER (4.76) | GRAVEL MINING OPERATION | NONE | 1.70 | 1.70 |
| MATTESE CREEK (4.76) | SANITARY | $BOD_5$, $NH_3$-N | .55 | 2.63-3.74 |
| BIG MUDDY (3.72) | SANITARY | $BOD_5$, $NH_3$-N | .33 | .46-.50 |
| LITTLE MUDDY (3.32) | SANITARY | $BOD_5$, $NH_3$-N | .41 | .53-.75 |
| BAYSHORE (2.10) | SANITARY | $BOD_5$, $NH_3$-N | .10 | .10 |
| POMME CREEK (2.00) | SANITARY | $BOD_5$, $NH_3$-N | .18 | .23-.32 |
| UNION ELECTRIC BOTTOM ASH (1.15) | POWER PLANT OPERATION | NONE | .65 | .65 |
| UNION ELECTRIC FLY ASH (1.15) | POWER PLANT OPERATION | NONE | 2.77 | 2.77 |
| UNION ELECTRIC REFUSE BOTTOM ASH (1.15) | POWER PLANT OPERATION | NONE | INTERMITTENT | INTERMITTENT |

* Insignificant Discharge

## B. WATER QUALITY

U.S.G.S. has maintained a sampling station at Paulina Hills since 1963. The station is located 0.3 mile downstream from Saline Creek and about 10 miles upstream of the Meramec's mouth. Table 7 lists average and maximum water quality values. "Average" values for dissolved oxygen (DO), temperature, and pH are derived from 117 samples collected monthly since 1963. Values reported for other substances are based on a period of record of seven years or less.

Other data reported in Table 7 includes the average and maximum values as determined in an EPA survey. The Missouri Clean Water Commission also assisted in this stream survey. Samples were collected at eleven different locations as listed in Table 8 on the Meramec for ten consecutive days from October 30 through November 8, 1973. The water quality indicators which were sampled included:

| | |
|---|---|
| Biochemical Oxygen Demand | BOD (mg/l, 5-day) |
| Chemical Oxygen Demand | COD (mg/l) |
| Dissolved Oxygen | DO (mg/l) |
| Total Ammonia Nitrogen | $NH_3$-N (mg/l as N) |
| Total Phosphorus | P (mg/l as P) |
| Total Nitrite and Nitrate | $NO_2$ & $NO_3$ -N (mg/l as N) |
| Temperature | °C |
| pH | — |
| Turbity | Meters |

Some heavy metals measurements were made at station 00268 which is immediately downstream of the major industrial discharges.

Of 117 measures of dissolved oxygen reported since 1963, only 9 of them have been less than 6.0 mg/l. They all occurred in the months of June, July, August and September and in all cases the stream temperature was at least 24°C. (75°F). The average daily stream flow in these cases ranged from 345 cfs to 2,180 cfs and were all

## TABLE 7

## INSTREAM WATER QUALITY

State: Missouri Basin: Meramec Segment: Mile 32 to Mouth Date: 10-30-73 through 11-8-73

| Description | Flow @ Eureka (cfs) | | DO (mg/1) | | BOD (mg/1) | | COD (mg/1) | | NH$_3$ (mg/1) | | NO$_2$ & NO$_3$ (mg/1) | | Temp °C | | pH | | Phos (mg/1) | | Phenols (mg/1) | | Heavy Metals (µg/1) | | Turbidity (meters) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Quality Standard | - | | 5.0 mg/1 | | - | | - | | 1.0 mg/1 @ pH=8.3 | | - | | 32°C | | 6.5-8.5 | | - | | - | | - | | - | |
| Sampling Stations | Ave. daily | Min. 7day 10yr. | Ave. | Min. | Ave. | Max. | Ave. | Max. | Ave. | Max. | Ave. | Max. | Ave. | Max. | Ave. | Max. (Min.) | Ave. | Max. | Ave. | Max. | Ave. | Max. | Ave. | Min. |
| Paulina Hills | 2968 | 280 | 9.35 | 3.90 (8-24-72) | - | - | 8.49 | 32.0 (4-18-72) | .038 | .20 (9-23-70) | (1) .49 | .75 | 14.8 | 31.1 (8-6-67) | 7.99 | 8.70 | .153 | .49 | - | - | See (2) | See (3) | 46.9 (mg/1 SiO2) | 460 (mg/1 SiO2) |
| 000272 | 2968 | 280 | 9.01 | 7.5 | 1.22 | 1.6 | 7.6 | 14 | .119 | .20 | .23 | .40 | 13.3 | 14.0 | 7.77 | 7.9 (7.6) | .112 | .15 | - | - | - | - | 20.0 | 10 |
| 000273 | 2968 | 280 | 8.91 | 7.4 | 1.10 | 1.5 | 9.4 | 14 | .110 | .16 | .19 | .30 | 13.7 | 14.0 | 7.71 | 7.9 (7.6) | .119 | .15 | - | - | - | - | 19.1 | 9 |
| 000274 | 2968 | 280 | 8.69 | 7.0 | 1.11 | 1.4 | 7.5 | 13 | .182 | .54 | .24 | .40 | 14.1 | 15.0 | 7.74 | 7.9 (7.5) | .133 | .25 | - | - | - | - | 17.1 | 8.4 |
| 000275 | 2968 | 280 | 8.67 | 7.1 | 1.18 | 2.1 | 10.4 | 17 | .171 | .53 | .21 | .40 | 14.3 | 15.0 | 7.74 | 8.0 (7.5) | .115 | .20 | - | - | - | - | 16.4 | 10.2 |
| 000276 | 2968 | 280 | 8.81 | 7.0 | 1.14 | 1.3 | 9.4 | 14 | .210 | .56 | .21 | .40 | 14.6 | 15.0 | 7.77 | 8.0 (7.6) | .130 | .31 | - | - | - | - | 16.4 | 10.0 |
| 000264 | 2968 | 280 | 10.3 | 9.3 | 1.97 | 3.4 | 17.1 | 28.0 | .097 | .24 | .27 | .50 | 10.2 | 12.5 | 7.66 | 8.1 (7.0) | .416 | 1.90 | - | - | - | - | 27.5 | 8 |
| 280586 | 2968 | 280 | 10.4 | 9.9 | 1.91 | 2.7 | 16.5 | 30.0 | .076 | .11 | .30 | .30 | 10.5 | 12.0 | 7.75 | 8.1 (7.3) | .226 | 1.35 | .9 | 3 | - | - | 26.7 | 11 |
| 000268 | 2968 | 280 | 9.93 | 9.3 | 1.37 | 2.0 | 8.44 | 16.0 | .107 | .27 | .20 | .40 | 11.9 | 13.0 | 7.71 | 7.9 (7.4) | .255 | 1.00 | 2.7 | 5 | Cr7.5<br>Pb70<br>Zn4.3 | Cr8.0<br>Pb70<br>Zn4.8 | 23.9 | 12 |
| 000269 | 2968 | 280 | 9.85 | 9.4 | 1.37 | 1.8 | 11.2 | 40.0 | .067 | .15 | .18 | .30 | 10.1 | 13.0 | 7.77 | 8.1 (7.5) | .136 | .27 | .7 | 3 | - | - | 17.7 | 9 |
| 000270 | 2968 | 280 | 9.38 | 8.2 | 1.29 | 1.7 | 10.1 | 17.0 | .099 | .20 | .21 | .40 | 12.3 | 13.0 | 7.77 | 7.9 (7.5) | .147 | .35 | - | - | - | - | 19.8 | 10 |
| 000271 | 2968 | 280 | 9.18 | 7.9 | 1.26 | 1.7 | 9.4 | 16 | .088 | .18 | .20 | .30 | 13.2 | 14.0 | 7.77 | 7.9 (7.6) | .121 | .31 | - | - | - | - | 19.6 | 10 |

(1) Average of 4 measurements since 1964, all other Paulina Hills averages, except Heavy Metals, are based on 44 samples or more since 1969 at the latest.

(2) Chromium: 0µg/1 (single measurement 12-8-71)
Dissolved Copper, Cu: 8.0µg/1 (single measurement 12-8-71)
Dissolved Lead, Pb: 7.0 µg/1
Dissolved Nickel, Ni: 5.0 µg/1 (single measurement 12-8-71)
Dissolved Zinc, Zn: 75 µg/1
Dissolved Cadmium, Cd: 3.5 µg/1

(3) Dissolved Cadmium, Cd: 6.0 µg/1
Dissolved Lead, Pb: 12.0 µg/1
Dissolved Zinc, Zn: 150 µg/1

Source: Combinatorics, Inc., (A Subsidiary of MATHEMATICA, Inc.), Load Allocation Study of the Lower Meramec River Basin, Lafayette, Indiana, June, 1974. (Ref: 11)

## TABLE 8

## MERAMEC RIVER SAMPLING STATIONS

| EPA "Storet" Number | River Mile from Mouth | Description |
|---|---|---|
| 000264 | 32 (approximate) | Walk in sample off gravel bar |
| 280586 | 22.47 | Walk in sample, knee deep |
| 000268 | 19.37 | Boat sample composited at quarter points |
| 000269 | 16.13 | Same as above |
| 000270 | 13.95 | Same as above |
| 000271 | 10.57 | Same as above |
| 000272 | 9.10 | Same as above |
| 000273 | 5.95 | Same as above |
| 000274 | 2.10 | Same as above |
| 000275 | 1 (approximate) | Same as above |
| 000276 | 0.0 (at mouth) | Same as above |

Source: Combinatorics, Inc., (A Subsidiary of MATHEMATICA, Inc.), Load Allocation Study of the Lower Meramec River Basin, Lafayette, Indiana, June, 1974. (Ref. 11) below the average daily flow based on 53 years of record. Only one sample was recorded below the standard of 5.0 mg/l, with a corresponding stream temperature of 27°C. and a flow of approximately 600 cfs.

Total ammonia as nitrogen was above 0.1 mg/l in 6 of 58 samples collected since 1968. The four highest values occured in the months of July, August and September, with the remaining two values occurring in April and December. The "permissive" (.5 mg/l) public water supply criterion for ammonia-N has never been exceeded in the seven year period for which records are available. The limited total nitrate and nitrite data shows that the stream concentration is quite low.

Total phosphorus as P, has not exceeded 0.5 mg/l in 44 samples collected since 1969, and has averaged 0.15 mg/l. The temperature of the Meramec ranges over wide values in any give year. Since 1963 the historical low is 0°C. and on two or three occasions the temperature has been as high as 30°C. There are no major thermal polluters located on the Meramec and the above variations are normal for the region's climate.

$BOD_5$data has not been collected at Paulina Hills in recent years, although COD data has been collected since 1967. The COD average for 64 samples is 8.5 mg/l, with a standard deviation of 7.0 mg/l indicating that COD has varied considerably in the last 8 years. On several occasions it has been very near zero, and had also reached a maximum of 32.0 mg/l on April 18, 1972. The streamflow at Eureka reported on that date was 35,400 cfs. The high COD was probably due to excessive land runoff and sewage plant overflows. Organic nitrogen, ammonia-nitrogen, and total phosphorus were all above average on that date, but their percentage increase was not as great as the percéntage increase of COD. Assuming that BOD would display the same increase as COD, it appears that land runoff, sewage treatment plant overflows, and resuspended creek deposits have a substantial effect on stream organics, particularly as caused by the larger rainstorms.

Data taken during the EPA survey substantiates the significant rise in pollutional loads during a rainstorm. Tributaries to the Lower Meramec were sampled daily at one location for BOD, $NH_3$-N and P. The maximum loads presented in Table 7 are those which were measured in a rainstorm of October 31, 1973 and were an order of magnitude greater than the average values for the survey.

Phenol was not reported at Paulina Hills, but was provided in an EPA survey performed in January 1973. The average value at sampling station 000268 was in fact larger than the 1.0 µg/l preferable limit for drinking water. Phenol cannot be easily removed from drinking water by conventional water treatment and combines with the chlorine disinfectant supplied to drinking water forming compounds that gives water an objectionable taste and odor. Phenol appears to be the most noticeable pollutant "problem" encountered in the Meramec.

Instream data for heavy metals is very sparce. Samples taken at Paulina Hills and station 00268 indicate no problem exists in meeting any of the generally accepted permissible criteria for surface waters used for public water supply. Analysis of the existing loads and loadings with implementation of BPT limits reveals that no problems presently exist or are expected to develop in the near future. Neither pH nor turbidity are outside the range of acceptable water quality standards.

Water quality of the Meramec is generally acceptable, except that the concentration of phenols in the mainstem is a problem if the river is used as a water supply.

Also under the existing discharge conditions, dissolved oxygen problems only occur at the extreme conditions of warm stream temperature and very low flows; however, under presently projected population trends and planning goal to eliminate discharge to creeks, the dissolved oxygen problem will become more pronounced. In addition, under low flow conditions, concentrations of $NH_3$ will increase to a level which violates acceptable water supply criteria.

## C. ALTERNATIVE TREATMENT PLANS

For the existing discharges any feasible load allocation for the Lower Meramec River Basin requires expensive advanced wastewater treatment to insure water quality standards are met under all conditions. It is possible to reduce these costs by instituting a regional system which treats all effluents at a single site. These savings are possible for the following reasons:

1. The economies of scale available with joint wastewater treatment.
2. The transfer of discharges downstream to a regional facility reduces the overall requirements for advanced waste treatment.

In addition, regionalization offers water quality benefits since a larger segment of the Meramec is freed of highly organic discharges. Regional facilities can afford to retain a better paid staff which generally leads to a well operated, highly efficient treatment facility, eliminating needless by-passing, and decreasing the probability of a complete breakdown in the treatment process. Finally, enforcement and surveillance costs are greatly reduced under regionalization.

However, implementing a regional system can be a time-consuming process and this is particularly true in the Lower Meramec where there exists no unified or designated body which could carry out a regional plan. Time required for negotiations between users, as well as the time required for the construction of long interceptors and larger centralized facilities will delay any regional abatement program.

The Lower Meramec is not exceptional in this respect since in general, the greater the regionalization, the greater the time required before facilities are completely operational. With such delays it is very probable that the 1977 compliance date will not be met.

Six stages (1 through 6) of regionalization were analyzed in the Lower Meramec (Figure 7), while Figures 8 through 13 depict the successive stages showing the required interceptor systems and the location of regional facilities.

In the most decentralized case (stage 1) it is assumed that with two exceptions a separate wastewater treatement facility serves each creek. Because of the ease with which joint treatment can be implemented, both Big Muddy and Little Muddy Creeks, and Pomme Creek and Bayshore have been combined. Even though stage 1 is the most decentralized case that was investigated, there was some aggregation of flows for two reasons. First, separate treatment requirements for individual discharges to the creeks would require modeling each creek independently. Second, discharges have been banned for several of the creeks and it is a generally accepted planning goal to remove all significant discharges from the creeks.

Each of the first three stages can be implemented by July, 1977; Stage 4 by 1978 and stages 5 and 6 by 1980. Since stage 5 is more expensive than stage 6 and the implementation time is equal, 5 was dropped from further investigation.

FIGURE 7

REGIONAL ALTERNATIVES FOR THE MERAMEC RIVER BASIN

(River Mile 22.5 to 0.0)

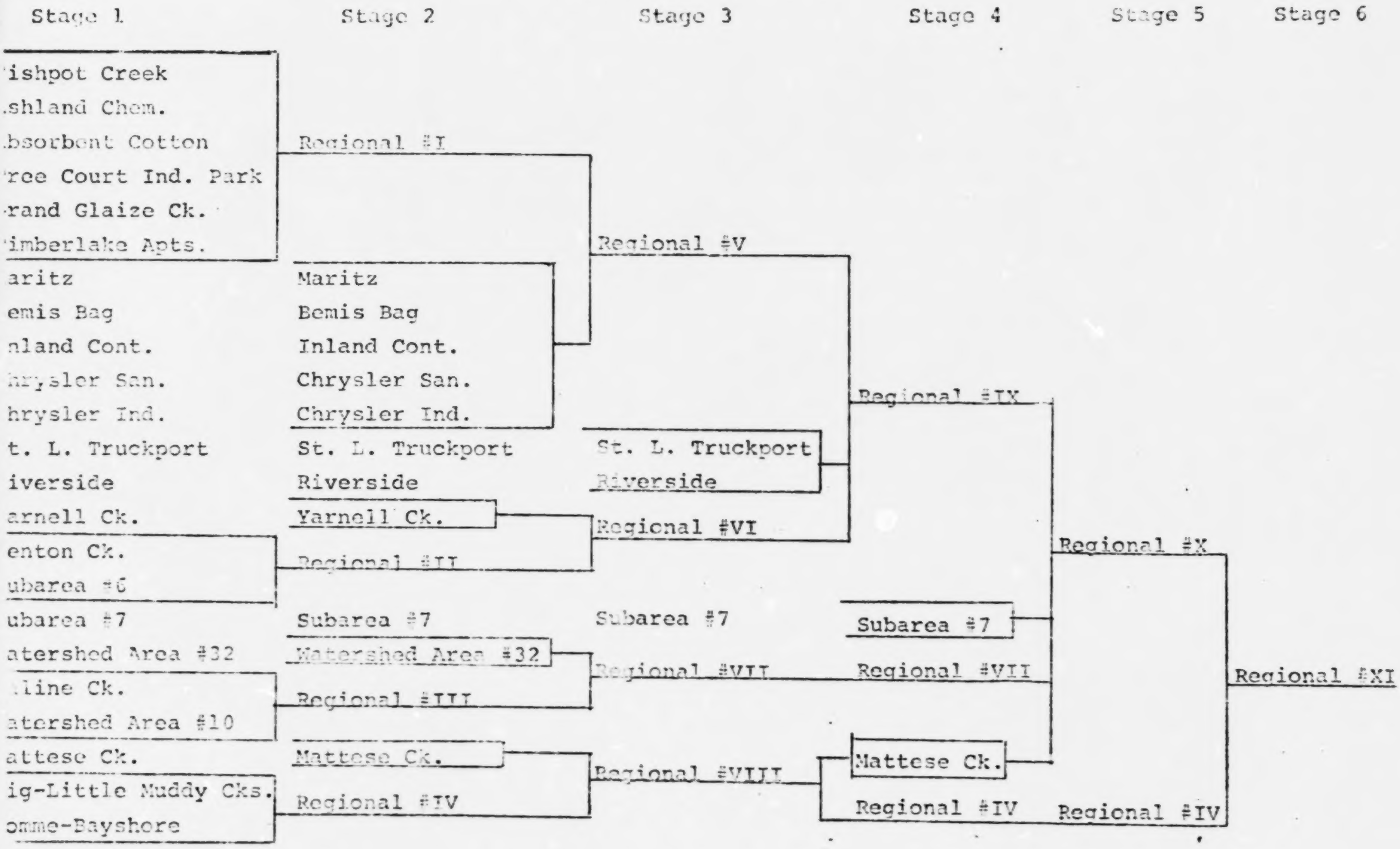


Figure 8

Regionalization - Stage 1

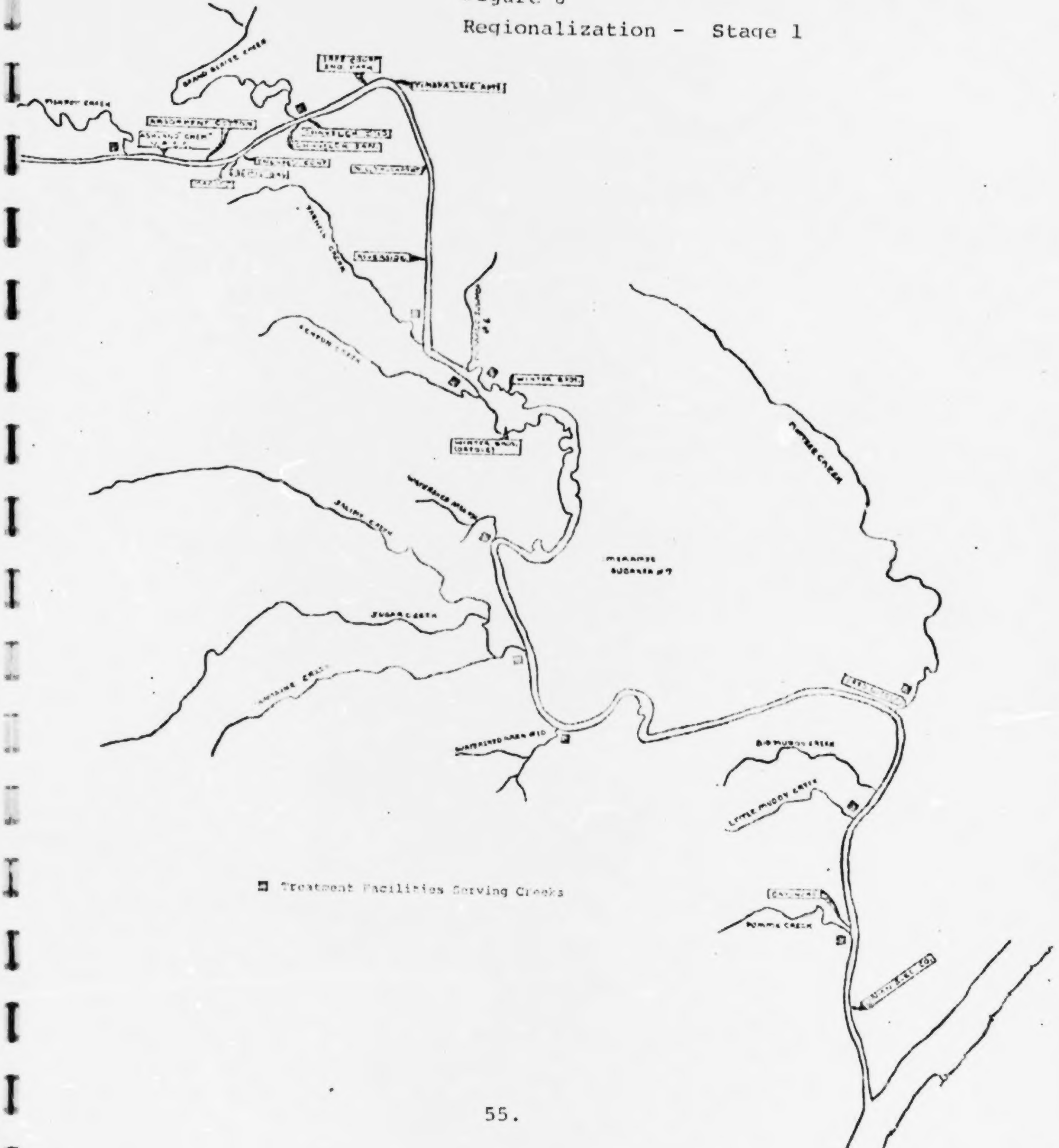


Figure 9
Regionalization - Stage 2

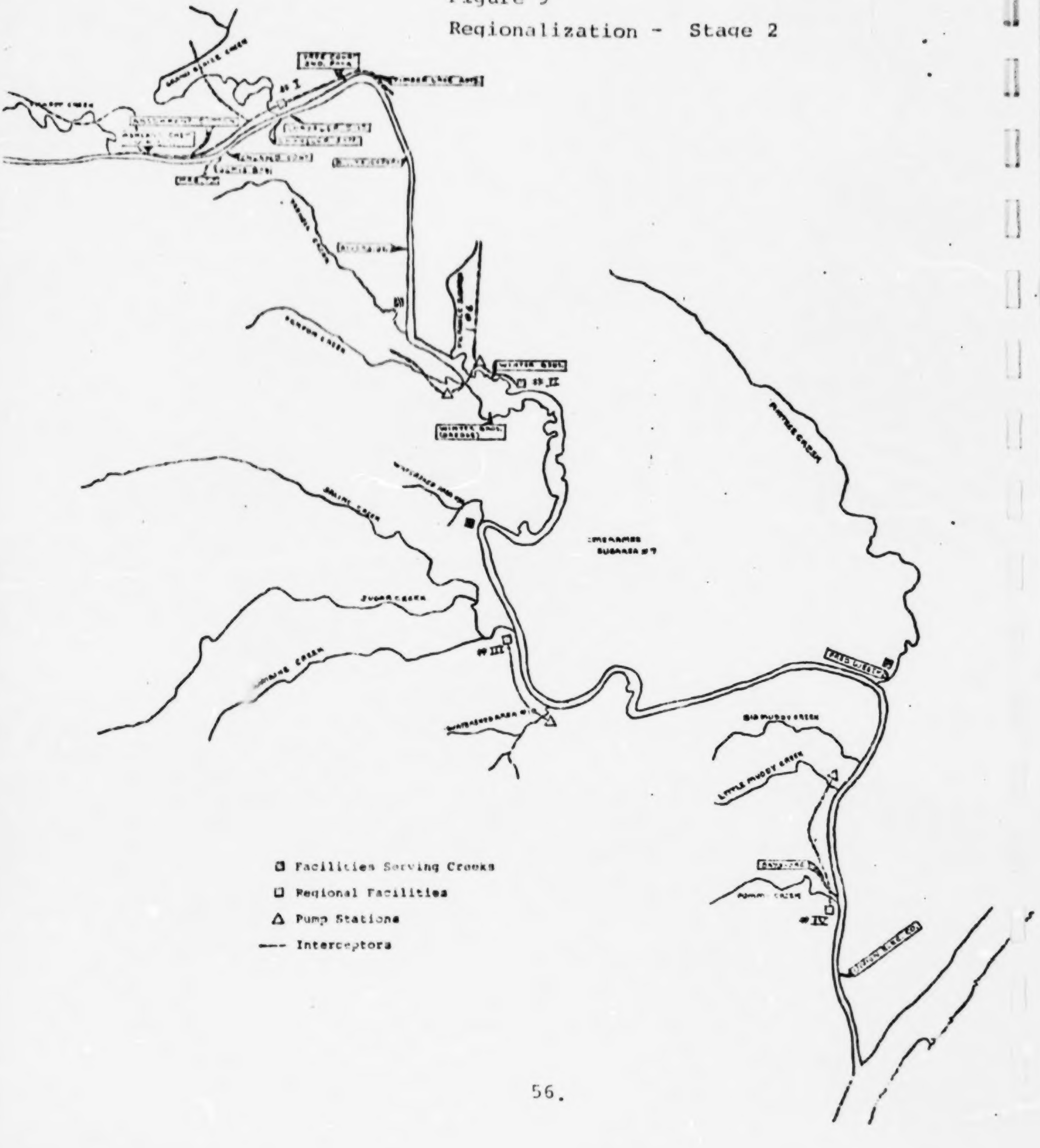


Figure 10
Regionalization - Stage 3

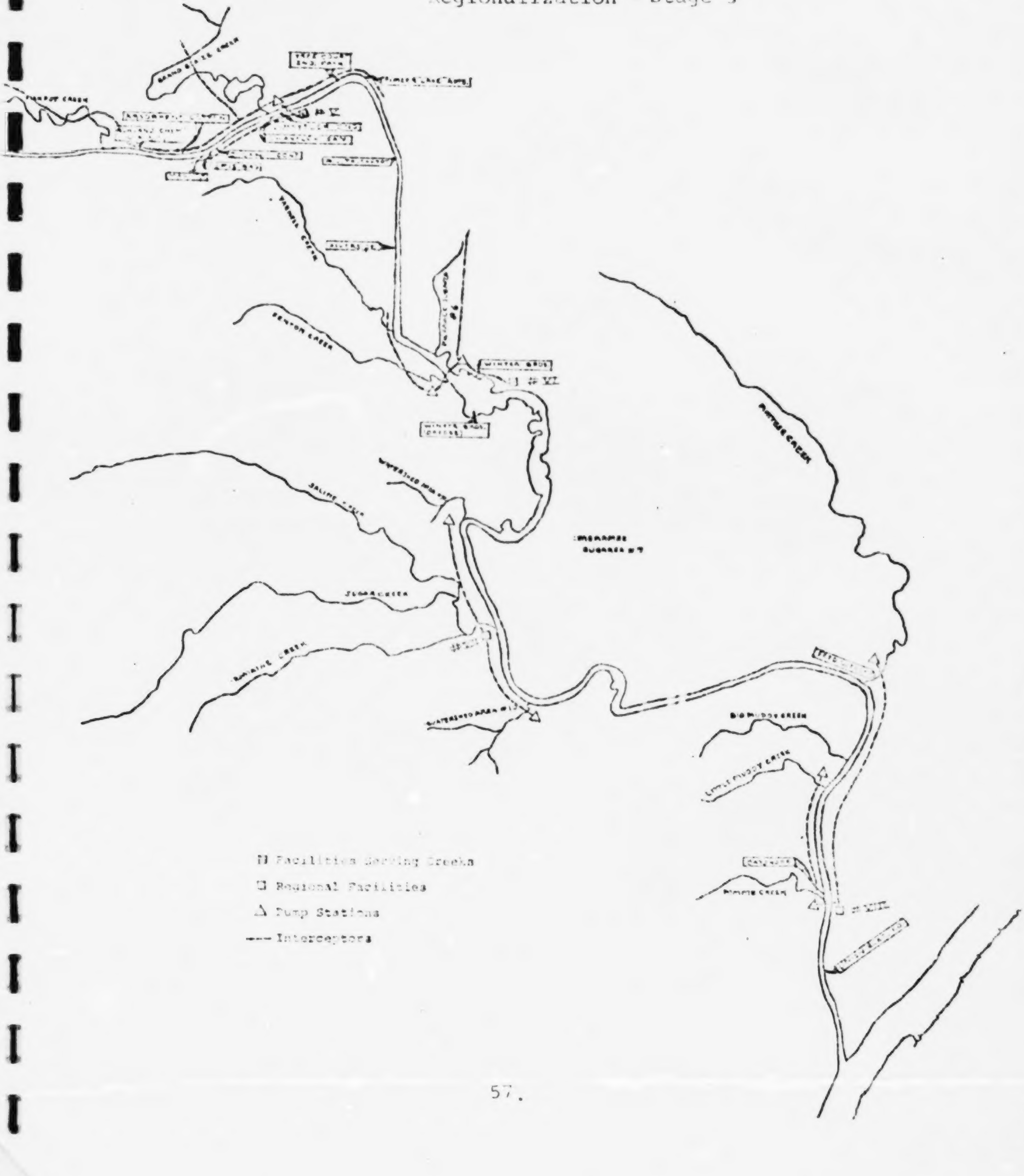


Figure 11
Regionalization - Stage 4

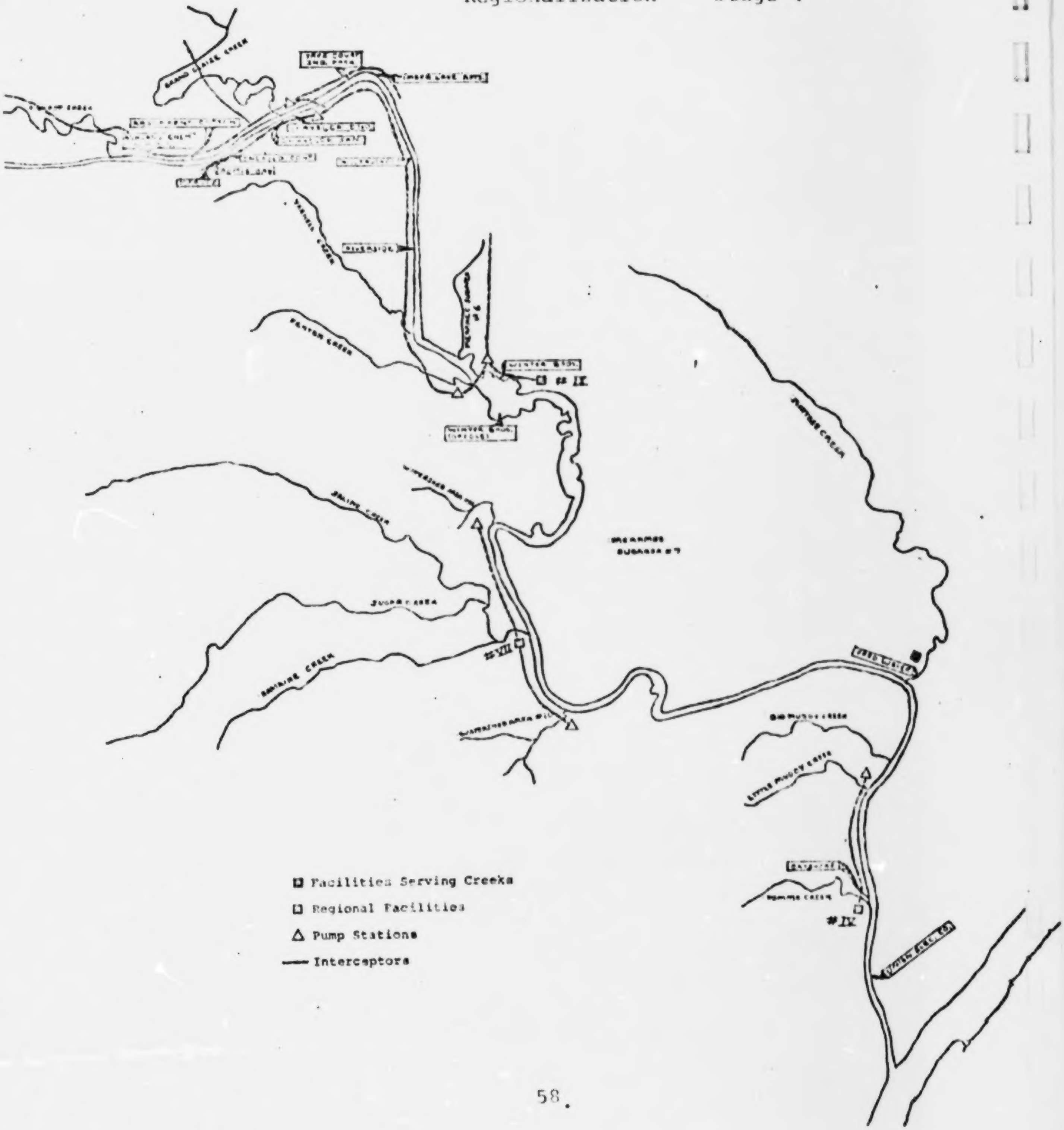


Figure 12

Regionalization - Stage 5

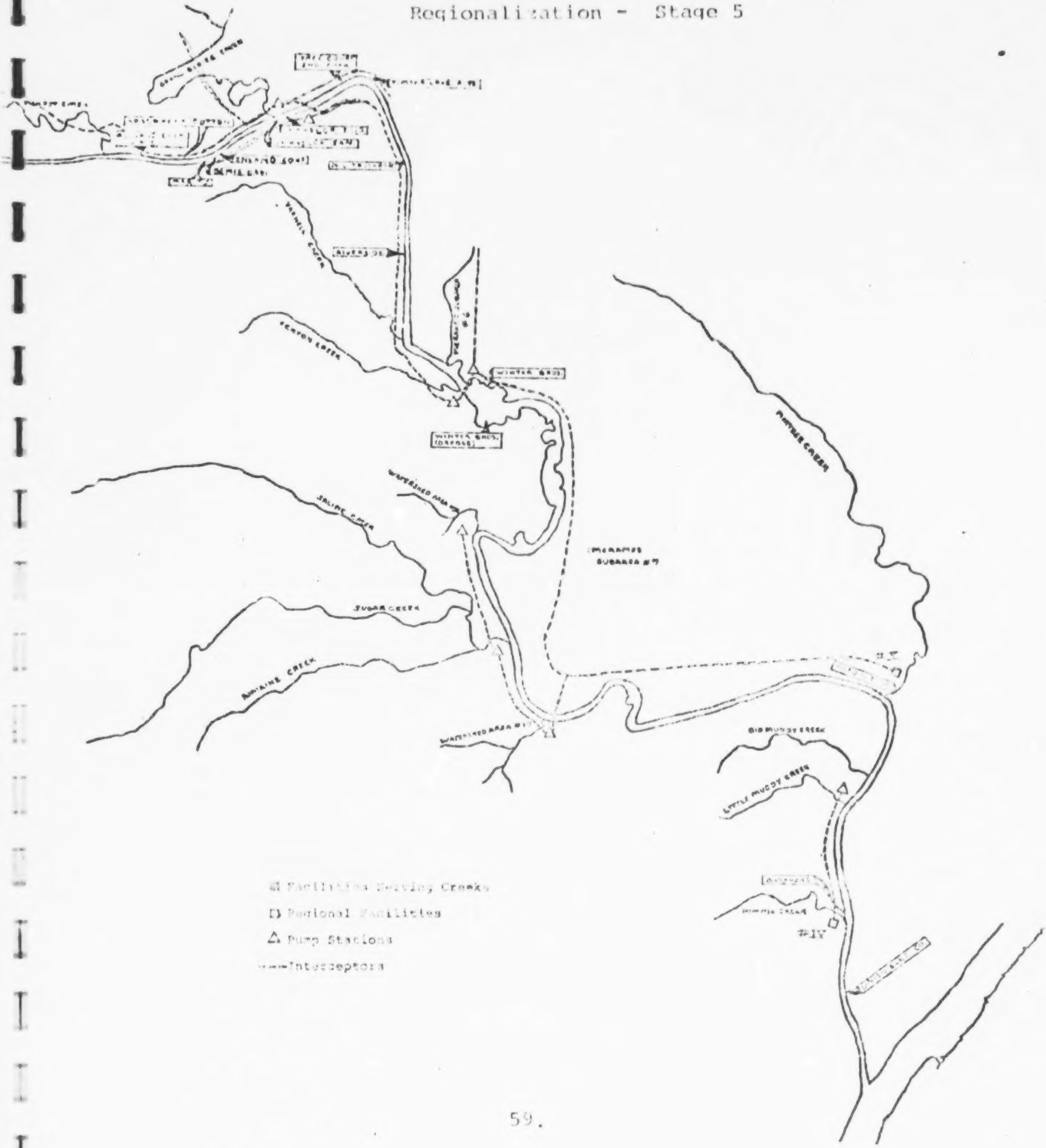
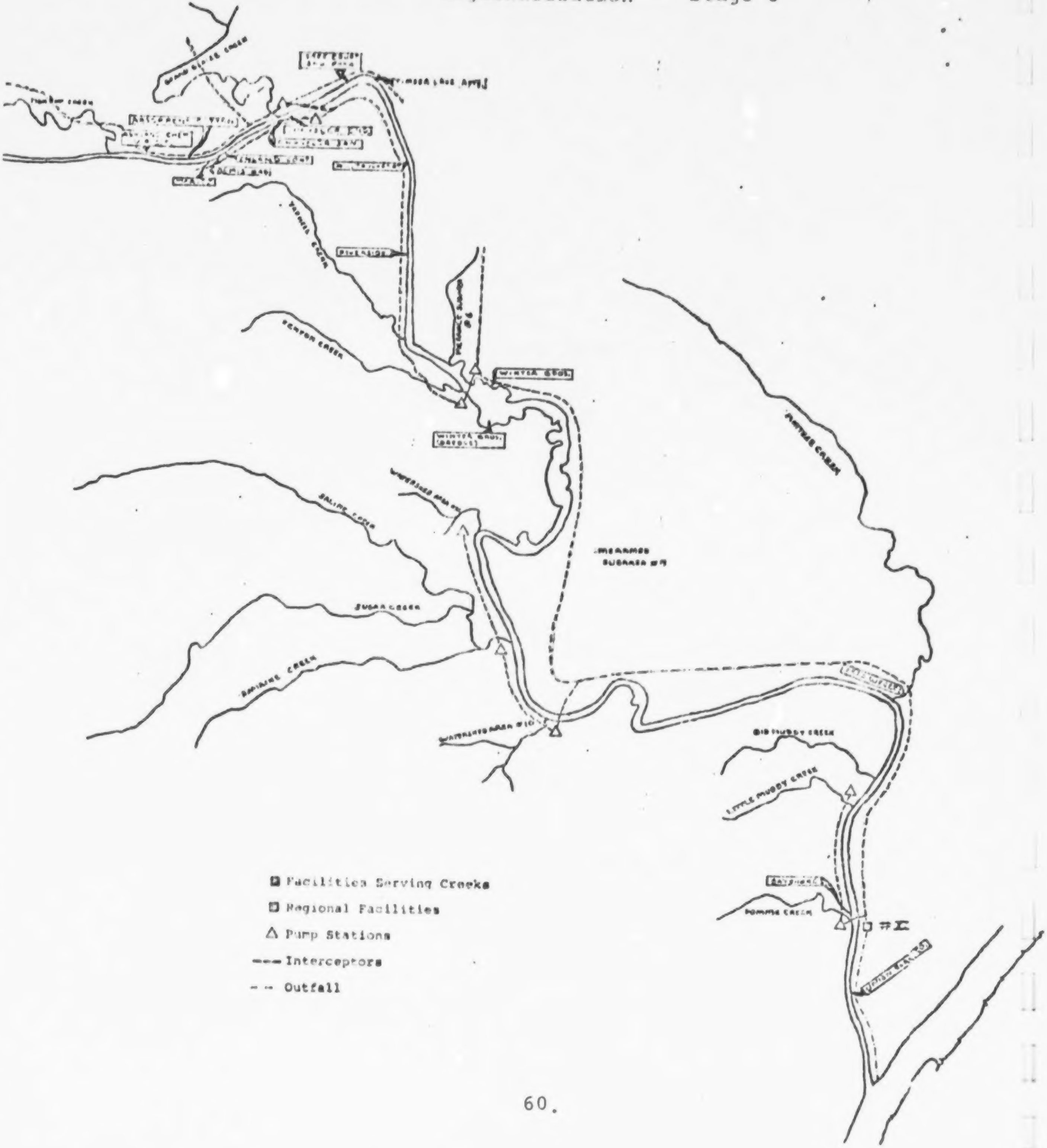


Figure 13
Regionalization - Stage 6



Also, assuming regionalization to be attractive, it was reasonable to investigate intermediate abatement procedures that would insure meeting the 1977 federal deadline and then allow for conversion to the complete regional abatement facilities. Therefore, in order to systematically investigate all feasible possibilities, nine scenarios were developed and analyzed. These scenarios consist of Stage 1 through 4 and 6 as long range solutions and Stage 1 through 4 as intermediate abatement procedures followed by conversion to Stage 6 at the end of a ten year period. These scenarios are summarized in Table 9.

## D. COST DATA

Cost estimates for each scenario were generated for the most cost effective abatement strategy for each stage. The MULQUAL (MULtiple QUALity river simulator) model was employed to allocate loads. The water quality simulation model is interfaced with a nonlinear optimization program which computes the least cost load allocation. The model utilized the cost functions described earlier and full descriptions of the model can be found in the Appendix. For the long range alternatives, assumed wastewater flows yield average cost over a twenty to thirty year period, while for intermediate alternatives, assumed wastewater flows yield average annual cost estimates over the next ten to twelve years. For any specified discharge configuration advanced wastewater treatment (AWT) requirements were determined using MULQUAL. Estimated costs of interceptors and minimum wastewater treatment levels (Secondary or BPT) were added to these AWT costs. The piping costs (Ref. 61) were based on full regionalization, since interceptors installed for intermediate decentralized stages would be useable in the ultimate regional system and would be designed for a full forty year life.

## TABLE 9

## DESCRIPTION OF TREATMENT ALTERNATIVES

| SCENARIO | DESCRIPTION | IMPLEMENTATION DATE | NUMBER OF LOCAL PLANTS | NUMBER OF REGIONAL PLANTS | INTERCEPTOR MILES |
|---|---|---|---|---|---|
| I | STAGE 1 | 1976 | 19 | 0 | 20 |
| II | STAGE 1<br>+ STAGE 6 | 1976<br>1986 | 19<br>0 | 0<br>1 | 20<br>50 |
| III | STAGE 2 | 1977 | 11 | 4 | 29 |
| IV | STAGE 2<br>+ STAGE 6 | 1977<br>1987 | 11<br>0 | 1<br>1 | 29<br>50 |
| V | STAGE 3 | 1977 | 3 | 4 | 37 |
| VI | STAGE 3<br>+ STAGE 6 | 1977<br>1987 | 3<br>0 | 4<br>1 | 37<br>50 |
| VII | STAGE 4 | 1978 | 2 | 3 | 37 |
| VIII | STAGE 4<br>+ STAGE 6 | 1978<br>1988 | 2<br>0 | 3<br>1 | 37<br>50 |
| IX | FULL REGIONALIZATION (STAGE 6) | 1980 | 0 | 1 | 50 |

Source: MATHEMATICA, Inc.

Cost for the various stages are presented in Tables 10 and 11.

In addition, the tradeoff between the cost of interceptors, primary and secondary treatment, and advanced waste treatment is shown in Figures 14 and 15.

The cost data confirmed the original hypothesis that aggregation of effluents and treatment in larger regional plants is less expensive.

In order to evaluate specific scenarios, the stage costs then had to be transformed to scenario costs. The cost for odd numbered scenarios is taken directly from the appropriate long range stage cost. The even numbered scenarios' cost were estimated by adding the investment cost from the appropriate intermediate stage plus the cost incurred ten years after for stage 6 minus the cost of the investment in piping previously expended to implement the intermediate stage. The O&M costs for the first ten years are taken from the appropriate intermediate stage data, while the O&M costs for the next twenty years are based on stage 6 operation. A summary of these costs is presented in Table 12.

Both the effect of inflation and demand stimulated price increases were included in the calculation of costs as would actually be incurred.

Investments were assumed to occur in a phased fashion over a three year period, with 10% required in the first year, 40% in the second year and 50% in the third year. Bonds were used to finance the municipal portion of the third year investment at a rate of 7% for twenty years.

## TABLE 10

## TOTAL COST, BY COST COMPONENT - ULTIMATE DESIGN

(All cost in 1974 dollars)

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Stage 6 |
|---|---|---|---|---|---|---|
| Estimated Annual O&M | 3,612,000 | 2,998,000 | 2,616,000 | 2,279,000 | 1,649,000 | 1,520,000 |
| Estimated Amortized Capital Cost | 3,799,000 | 3,730,000 | 3,805,000 | 3,862,000 | 3,680,000 | 3,604,000 |
| Total Annual Cost | 7,411,000 | 6,728,000 | 6,421,000 | 6,141,000 | 5,329,000 | 5,124,000 |
| Interceptors & Pumping | 2,088,000 | 7,993,000 | 13,288,000 | 16,372,000 | 20,796,000 | 21,439,000 |
| Treatment Facilities | 38,461,000 | 31,819,000 | 27,326,000 | 24,859,000 | 17,489,000 | 16,421,000 |
| Estimated Capital Cost | 40,549,000 | 39,812,000 | 40,614,000 | 41,231,000 | 38,285,000 | 37,860,000 |

Source: MATHEMATICA, Inc.

TABLE 11

TOTAL COST BY COMPONENT-INTERMEDIATE DESIGN

(All cost in 1974 dollars)

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 |
|---|---|---|---|---|---|
| Estimated Annual O&M | 2,449,000 | 2,032,000 | 1,609,000 | 1,615,000 | 1,164,000 |
| Estimated Amortized Capital Cost | 2,790,000 | 2,786,000 | 2,863,000 | 3,148,000 | 3,154,000 |
| Total Annual Cost | 5,239,000 | 4,818,000 | 4,472,000 | 4,763,000 | 4,318,000 |
| Interceptors & Pumping | 2,088,000 | 7,933,000 | 13,288,000 | 16,372,000 | 20,796,000 |
| Treatment Facilities | 27,697,000 | 21,748,000 | 17,279,000 | 17,230,000 | 11,867,000 |
| Estimated Capital Cost | 29,785,000 | 29,741,000 | 30,567,000 | 33,602,000 | 32,663,000 |

Source: MATHEMATICA, Inc.

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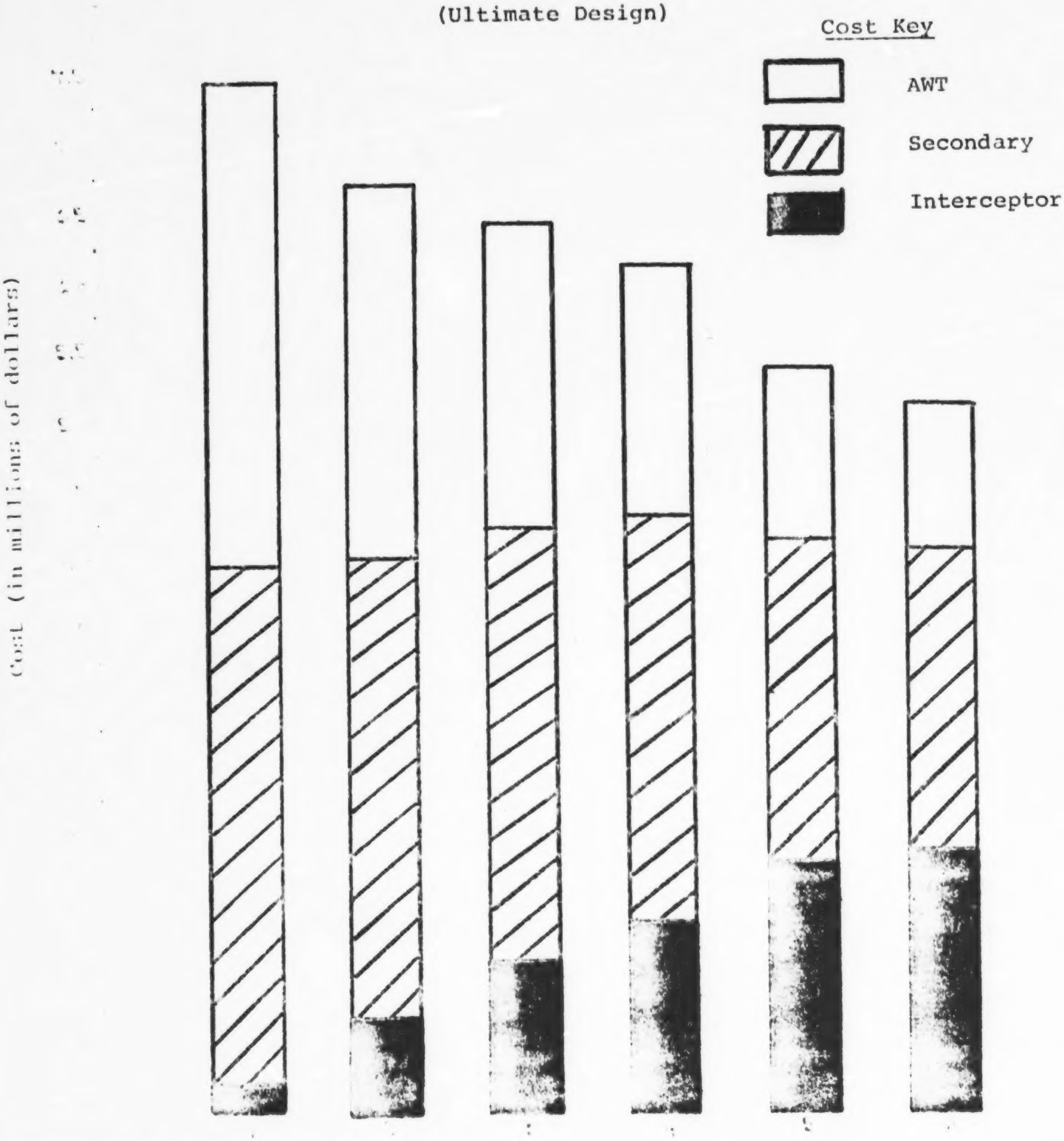
FIGURE 14

MERAMEC COST COMPONENTS

(Ultimate Design)

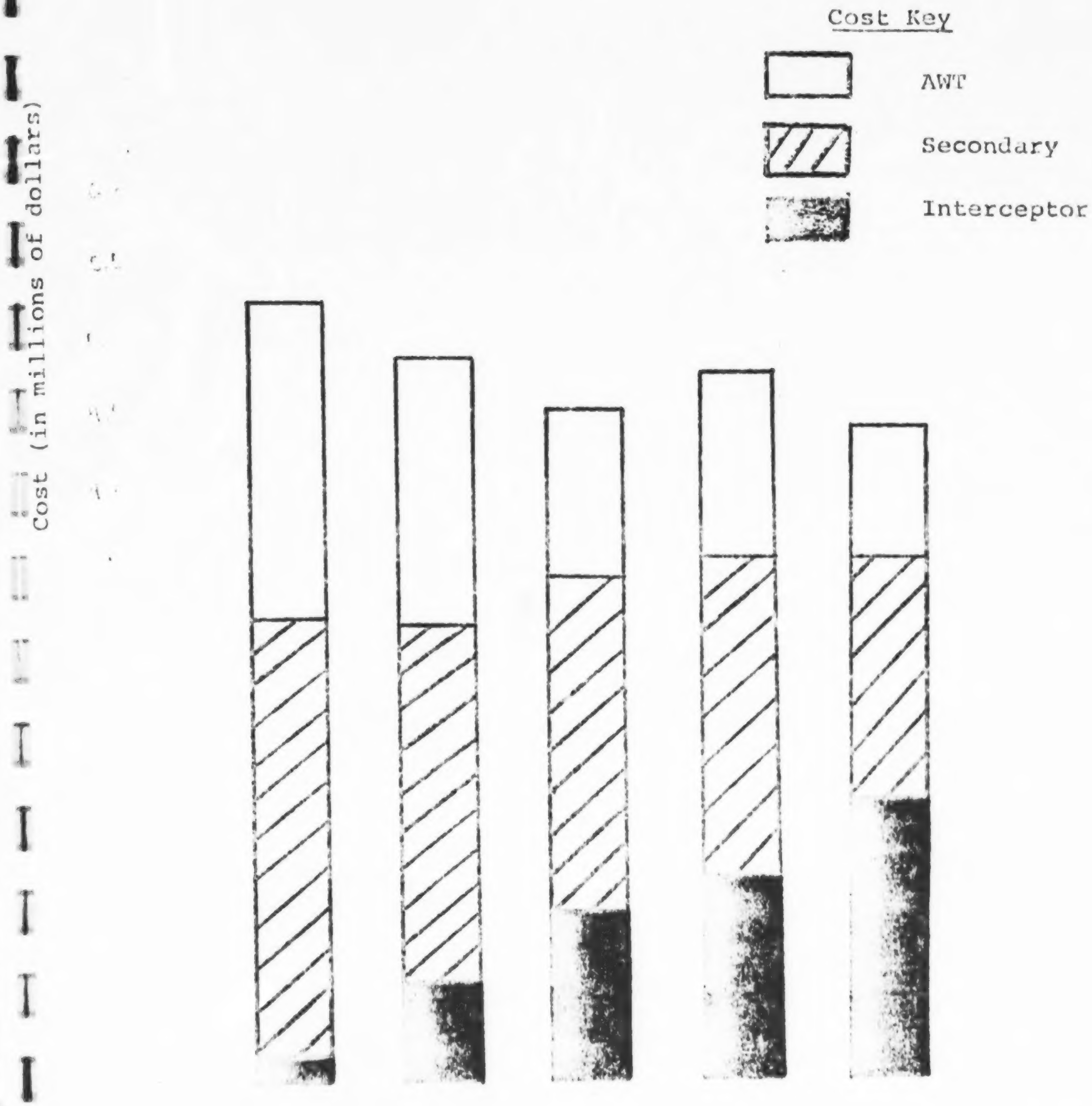


Source: MATHEMATICA, Inc.

FIGURE 15

MERAMEC COST COMPONENTS

(Intermediate Design)



Source: MATHEMATICA, Inc.

## TABLE 12

## COST ALTERNATIVES

## 1974 DOLLARS

| SCENARIO | INVESTMENT REQUIRED | IMPLEMENTATION DATE | ANNUAL O&M | PERIOD OF SERVICE |
|---|---|---|---|---|
| I | $40,600,000 | 1976 | $3,610,000 | 1976-2006 |
| II | 29,800,000<br>35,800,000 | 1976<br>1986 | 2,450,000<br>1,520,000 | 1976-1986<br>1987-2006 |
| III | 39,800,000 | 1977 | 3,000,000 | 1977-2007 |
| IV | 29,700,000<br>29,900,000 | 1977<br>1987 | 2,030,000<br>1,520,000 | 1977-1987<br>1988-2007 |
| V | 40,600,000 | 1977 | 2,620,000 | 1977-2007 |
| VI | 30,600,000<br>24,600,000 | 1977<br>1987 | 1,610,000<br>1,520,000 | 1977-1987<br>1988-2007 |
| VII | 41,200,000 | 1978 | 2,230,000 | 1978-2008 |
| VIII | 33,600,000<br>21,500,000 | 1978<br>1988 | 1,620,000<br>1,520,000 | 1978-1988<br>1989-2008 |
| IX | 37,860,000 | 1980 | 1,520,000 | 1980-2010 |

Source: MATHEMATICA, Inc.

The cost as incurred are given in Table 13. The present worth of those cash flows, determined by assuming a thirty year facilities life, is shown in Table 14.

Scenario IX is the most economically attractive alternative saving over $15 million over the next best alternative. It has a three year delay for meeting the federal deadline, while Scenario VI is the least costly solution which meets the federal compliance deadline of July 1, 1977. Sceanrio VI requires that an interim regional system be implemented by 1971 and then upgraded to a full regional system by 1987. While slightly less costly then Scenario V, the scenario is much more complex and somewhat atypical. In order to preserve the generality and therefore relevance of the study, Scenario V was chosen for detailed analysis. This does not in any way effect the conclusion or the validity of the study, but does increase the applicability of the results. Clearly, comparison of Scenarios V and IX explify the issues involved in this report. Therefore, only Scenario V and Scenario IX will be considered in the remaining analysis.

## E. PROJECTED WATER QUALITY

Water quality conditions under Scenario V and under Scenario IX were modeled. Since Scenario IX is to be completed in 1980, it is necessary to compare water quality in both 1977 and 1980. As shown in Table 15 in 1977 when compared to Scenario V, Scenario IX discharges an additional daily load of 1612 lbs/day of $BOD_5$ and 465 lbs/day of ammonia as N. However, Scenario IX's daily loads do provide some reduction of existing BOD, $NH_3$-N and phenols loads. The expected loads are based on the following interim abatement plan which could be employed by 1977 at minimal additional cost:

1. Maintain all creek discharges at existing location until the regional system is available.
2. Take steps to insure secondary treatment as defined in the federal register is consistently maintained for all sanitary discharges.
3. Develop pretreatment operation which will significantly reduce the carbonaceous BOD load for industrial wastewater discharges.
4. Abate phenols to insure the river is an acceptable water supply for industrial wastewater discharges.

# TABLE 13

COST AS INCURRED
(MILLIONS OF DOLLARS)

| SCENARIO / YEAR | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | LAST YEAR COST (YEAR) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I CAPITAL (L.R.) | 4.96 | 17.6 | 11.9 | .134 | . | . | . | . | . | . | . | . | . | . | . | . | .134 (1996) |
| I O&M (L.R.) | | | | 4.55 | - | - | - | - | - | - | - | - | - | - | - | - | 14.19 (2006) |
| II CAPITAL (INTER) | 2.93 | 13.0 | 8.81 | .833 | . | . | . | . | . | . | . | . | . | . | . | . | .833 (1996) |
| II CAPITAL (L.R.) | | | | | | | | | | | 7.76 | 32.52 | 22.03 | 2.14 | . | . | 2.17 (2006) |
| II O&M (INTER) | | | | 3.09 | - | - | - | - | - | - | - | - | 4.39 | | | | 4.39 (1986) |
| II O&M (L.R.) | | | | | | | | | | | | | | 3.06 | - | - | 6.46 (2006) |
| III CAPITAL (L.R.) | | 4.34 | 18.3 | 12.6 | 1.20 | . | . | . | . | . | . | . | . | . | . | . | 1.20 (1997) |
| III O&M (L.R.) | | | | | 4.08 | - | - | - | - | - | - | - | - | - | - | - | 12.72 (2007) |
| IV CAPITAL (INTER) | | 3.24 | 13.9 | 9.43 | .96 | . | . | . | . | . | . | . | . | . | . | . | .96 (1997) |
| IV CAPITAL (L.R.) | | | | | | | | | | | | 7.00 | 30.81 | 20.41 | 1.92 | . | 1.97 (2007) |
| IV O&M (INTER) | | | | | 2.76 | - | - | - | - | - | - | - | - | 3.93 | | | 3.93 (1987) |
| IV O&M (L.R.) | | | | | | | | | | | | | | | 3.18 | - | 6.70 (2007) |
| V CAPITAL (L.R.) | | 4.43 | 19.16 | 12.9 | 1.22 | . | . | . | . | . | . | . | . | . | . | . | 1.22 (1997) |
| V O&M (INTER) | | | | | 3.55 | | | | | | | | | | | | 11.11 (2007) |
| VI CAPITAL (INTER) | | 3.34 | 14.4 | 9.74 | .92 | . | . | . | . | . | . | . | . | . | . | . | .92 (1997) |
| VI CAPITAL (L.R.) | | | | | | | | | | | | 5.76 | 24.98 | 16.00 | 1.59 | . | 1.63 (2007) |
| VI O&M (INTER) | | | | | 2.19 | - | - | - | - | - | - | - | - | 3.11 | | | 3.11 (1987) |
| VI O&M (L.R.) | | | | | | | | | | | | | | | 3.18 | - | 6.70 (2007) |
| VII CAPITAL (L.R.) | | | .87 | 21.01 | 14.6 | 1.33 | . | . | . | . | . | . | . | . | . | . | 1.33 (1998) |
| VII O&M (L.R.) | | | | | | 3.28 | - | - | - | - | - | - | - | - | - | - | 10.23 (2008) |
| VIII CAPITAL (INTER) | | | 3.97 | 17.1 | 11.47 | 1.08 | . | . | . | . | . | . | . | . | . | . | 1.08 (1998) |
| VIII CAPITAL (L.R.) | | | | | | | | | | | | | 5.44 | 23.43 | 15.6 | 1.50 | 1.54 (2008) |
| VIII O&M (INTER) | | | | | | 2.35 | - | - | - | - | - | - | - | - | 3.34 | | 3.34 (1988) |
| VIII O&M (L.R.) | | | | | | | | | | | | | | | | 3.31 | 6.97 (2008) |
| IX O&M (L.R.) | | | | | 3.17 | 22.3 | 13.11 | 1.43 | . | . | . | . | . | . | . | . | 1.45 (2000) |
| IX O&M (L.R.) | | | | | | | | 2.01 | - | - | - | - | - | - | - | - | 8.14 (2010) |

Source: MATHEMATICA, Inc.

. . . represents stream of equal [illegible]

- - - represents stream of O&M cost inflated at 4% a year

L.R. Long Range

Inter. [illegible]

TABLE 14

TOTAL COST COMPARISONS

| SCENARIO | PRESENT VALUE OF ALL COSTS |
|---|---|
| I | $103,180,000 |
| II | 99,230,000 |
| III | 88,990,000 |
| IV | 89,850,000 |
| V | 85,780,000 |
| VI | 81,760,000 |
| VII | 79,390,000 |
| VIII | 81,010,000 |
| IX | 63,540,000 |

Source: MATHEMATICA, Inc.

## TABLE 15

## WATER QUALITY

(Average Daily Loads)
(pounds/day)

| SCENARIO | BOD | | AMMONIA-N | | PHENOLS | | PHOSPHORUS* | |
|---|---|---|---|---|---|---|---|---|
| | 1977 | 1980 | 1977 | 1980 | 1977 | 1980 | 1977 | 1980 |
| V | 2550 | 2690 | 635 | 762 | 2 | 2 | 1800 | 2190 |
| IX | 3862 | 3160 | 1100 | 540 | 2 | 2 | 1800 | 2190 |

*No Phosphorus Treatment

Source: MATHEMATICA, Inc.

Both scenarios require major investments to protect dissolved oxygen. Figures 16 and 17 depict projected DO profiles in 1977 and 1980 respectively. The profiles are at critical water quality conditions of 7-day, 10 year low flow, a stream temperature of 28°C, pH of 8.3, and maximum allowable discharges.

In 1977 and 1980 Scenario V would maintain dissolved oxygen above the minimum standard of 5.0 mg/l at the critical flow condition. Scenario IX would allow the dissolved oxygen to drop slightly below 4.0 mg/l at the sag in 1977. However, in 1980 elimination of all organic discharges until river mile 1.15 maintains a dissolved oxygen concentration above 6.0 mg/l above that location.

Water quality in the creeks would not significantly improve under Scenario IX until 1980. With the many small domestic wastewater facilities discharging to the creeks, close control would be required to prevent a health hazard.

## F. RESULTS

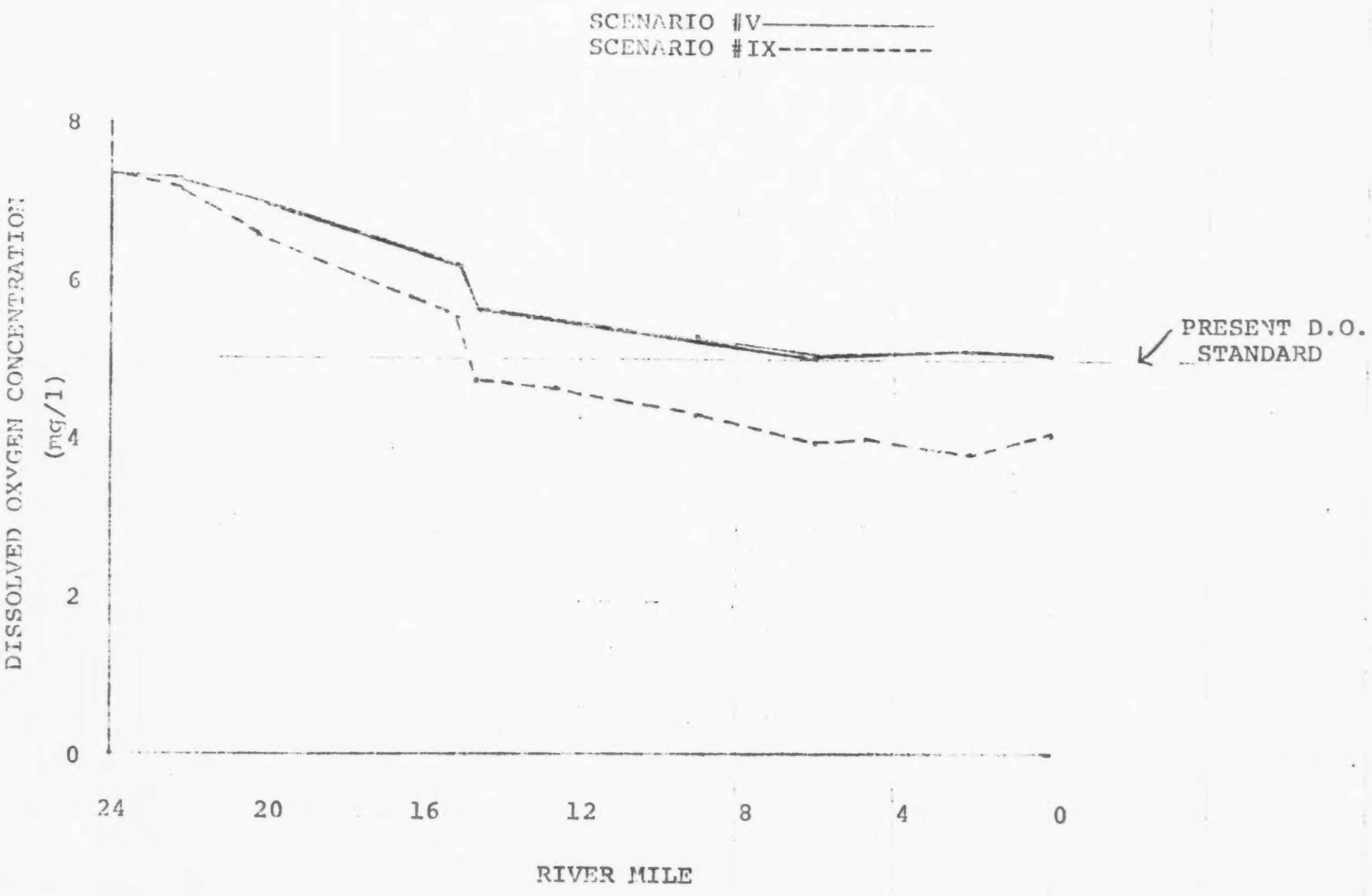
In the Meramec the three year delay results in both significant savings in wastewater treatment cost and long term benefits in water quality. Over the short term water quality is not abated. The effects of the three year delay period are shown in Table 16. The present worth is computed for cash flows out to the year 2000.

As shown in Table 16 under Scenario IX Ammonia-N loads are reduced by almost 30%, while $BOD_5$ is increased by approximately 17%. Thus it is possible to increase minimum DO standards to 75% of saturation and the standards in the Meramec could be upgraded after 1980. The environmental cost of this action is a slightly larger oxygen demand passed downstream to the Mississippi River. However, the effects to the larger Mississippi would be negligible. Scenario IX would support attempts to establish the "Lower Meramec River National

FIGURE 16

WATER QUALITY-1977

COMPARISON OF DISSOLVED OXYGEN PROFILE

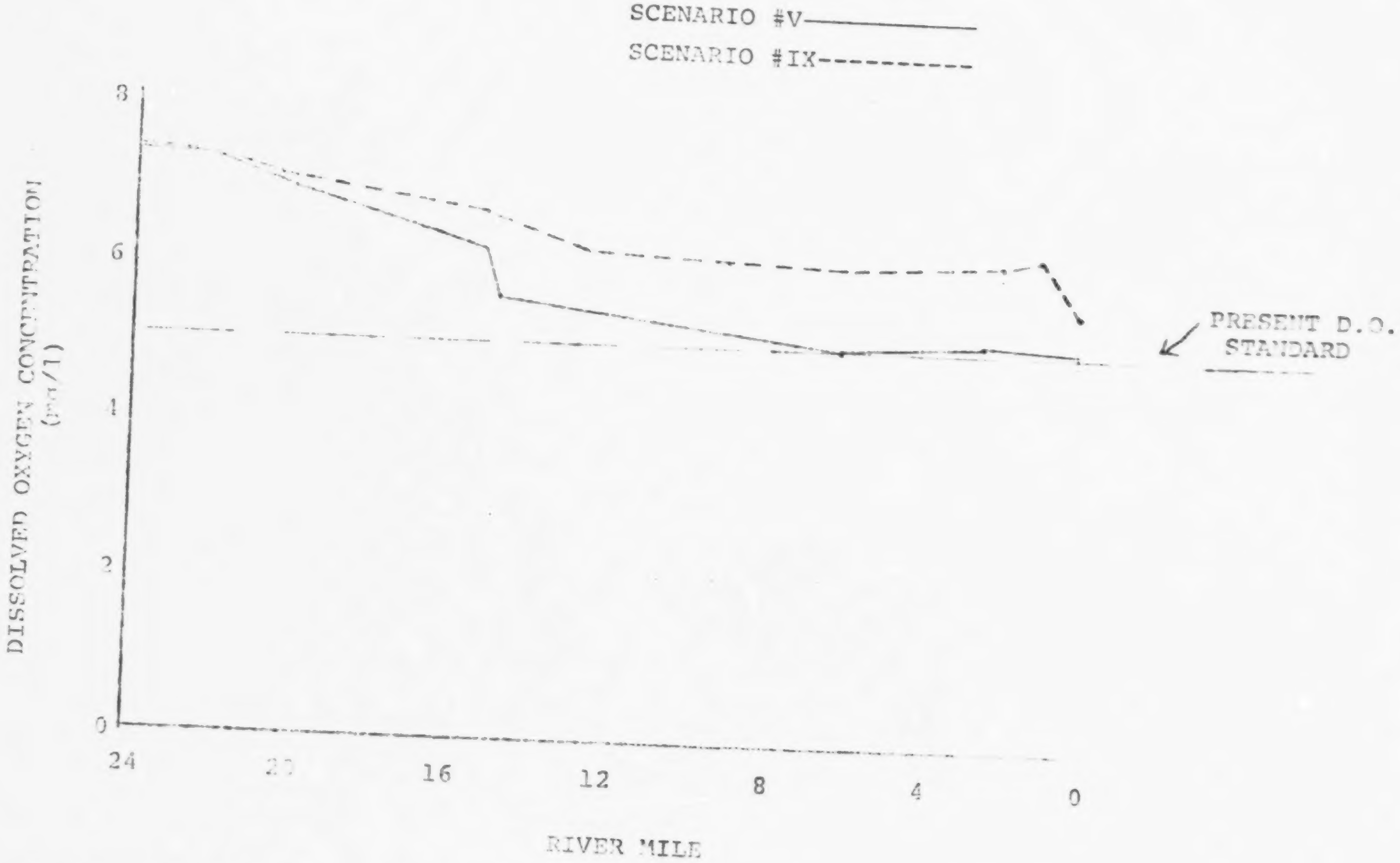


Source: Combinatorics, Inc., (A subsidiary of MATHEMATICA, Inc.), Load Allocation Study of the Lower Meramec River Basin, Lafayette, Indiana, June, 1974.

FIGURE 17

WATER QUALITY-1980

COMPARISON OF DISSOLVED OXYGEN PROFILE



Source: Combinatorics, Inc., (A Subsidiary of MATHEMATICA, Inc.), Load Allocation Study of the Lower Meramec River Basin, Lafayette, Indiana, June, 1974.

TABLE 16

## Summary of Results of Delay Period

| Present Worth (x$10^6$\$) | Benefits (x$10^6$\$) | Cost (Addition lbs. of Pollutants) | |
|---|---|---|---|
| Scenario #V 79.9<br>Scenario #IX 60.9 | Savings of 19.0<br>19.0 | $BOD_5$<br>$NH_3$-N<br>Phenols | +1,765,000<br>+ 509,175<br>No Difference |

Recreation Area". The area is well suited for camping, biking, trail riding, scenic enjoyment, small craft boating, fishing and swimming. In view of current energy problems, the establishment of a national recreation area in the proximate St. Louis area would be especially valuable in providing recreation while conserving gasoline reserves.

One additional benefit which total regionalization provides is the greater potential for an equitable allocation of costs, since the costs of a single regional system can be allocated to assure some degree of equity. A more decentralized approach could be less equitable because varying degrees of AWT would be required of the various municipal discharges.

## G. SENSITIVITY STUDIES

A series of sensitivity studies were performed to test the degree to which the savings brought about by regionalization are affected by changes in the basic study assumptions. The following parameters were examined; discount rate, long term inflation, short term inflation, amortization, municipal investment, total investment, annual investment/O&M cost, interceptor cost/treatment cost, and the impact of Best Available Treatment (BAT). Each factor is discussed below and summarized in Table 17.

Sensitivity is defined as the ratio of the change in output divided by the nominal output to the change in input divided by the nominal output. The "nominal case" output is the 23.8% saving resulting from a three year delay in compliance under the basic conditions and assumptions specified in previous discussions. Percentage reduction in costs is the measure of output.

## Discount Rate

A discount rate of 8% was used for the basic analysis. The savings were recomputed for values of 7, 10, and 12%. Savings increase to 32% at a 7% rate and decrease to 21% at a 12% rate. Sensitivities as defined above were calculated. For a 7% discount rate the sensitivity is:

$$s = \frac{(23.8 - 21.4)/23.8}{(.08 - .07)/.08} = 0.52$$

That is a one per cent change in the value of the discount rate and results in a 0.52 per cent change in the percentage savings for discount rates near 8%. For a 12% discount rate, sensitivity is 0.35. Therefore, while the conclusions are sensitive to changes in the discount rate, even under extreme rate changes a 20% cost reduction is still possible.

## Long Term Inflation Rates

Changing the long term inflation rate from 4% to 8% increased savings from 24% to 28%. With a sensitivity of .52 long term inflation rates are very important to the analysis. However, it is unlikely that long term rates will drop below value of 4%.

## Short Term Inflation Rates

The short term rate was found to have a significant impact on the study results particularly as rates increased. At 12%, the savings dropped from 24% to 15%, the lowest value computed. The sensitivity to short term inflation was found to be 0.49.

## TABLE 17

## SUMMARY OF SENSITIVITY ANALYSIS

| Parameter & Value | Life Cycle Costs 1977 Compliance (million $) | Life Cycle Costs 1980 Compliance (million $) | Savings as a Percentage of 1977 Cost |
|---|---|---|---|
| Base Case | 79.87 (nominal case) | 60.88 (nominal case) | 23.8 |
| Discount Rate, 7% | 82.98 | 65.22 | 21.4 |
| Discount Rate, 10% | 74.40 | 53.47 | 28.1 |
| Discount Rate, 12% | 69.59 | 47.25 | 32.1 |
| Long Term Inflation Rate, 8% | 103.22 | 74.41 | 27.9 |
| Short Term Inflation Rate, 4% | 66.14 | 45.02 | 31.9 |
| Short Term Inflation Rate, 12% | 95.80 | 81.43 | 15.0 |
| Amortization 5% Rate | 78.44 | 59.57 | 24.0 |
| Amortization 10% Rate | 82.18 | 63.05 | 23.3 |
| Amortization 12% Rate | 83.83 | 64.61 | 22.9 |
| Municipal Investment % of Total, 15% | 80.16 | 61.15 | 23.7 |
| Municipal Investment % of Total, 10% | 80.32 | 61.30 | 23.7 |
| Total Investment, 10% increase | 83.90 | 64.68 | 22.9 |
| Total Investment, 10% decrease | 75.84 | 57.08 | 24.7 |

TABLE 17 (continued)

SUMMARY OF SENSITIVITY ANALYSIS

| Parameter & Value | Life Cycle Costs 1977 Compliance (million $) | Life Cycle Costs 1980 Compliance (million $) | Savings as a Percentage of 1977 Cost |
|---|---|---|---|
| Total Investment, 20% increase | 87.95 | 68.47 | 22.2 |
| Total Investment, 20% decrease | 71.80 | 53.29 | 25.8 |
| Annual Investment/ O&M 10% increase | 78.43 | 59.89 | 23.6 |
| Annual Investment/ O&M 10% decrease | 81.36 | 61.77 | 24.1 |
| Interceptor Cost/ Treatment Cost 10% increase | 81.20 | 63.19 | 22.8 |
| Interceptor Cost/ Treatment Cost 10% decrease | 78.56 | 58.66 | 24.9 |
| Interceptor Cost/ Treatment Cost 20% increase | 82.52 | 65.19 | 21.7 |
| Interceptor Cost/ Treatment Cost 20% decrease | 77.23 | 56.49 | 26.0 |

Source: MATHEMATICA, Inc.

### Financing Interest Rate

Borrowing rates for bonds were varied from 5% to 12%. The rate only applies to that portion of investment financed by bonds, and has minimal impact on savings. In this study, 75% of investment will be paid by the federal government with only 25% requiring bonding. Changes in savings were minimal and these savings are only slightly sensitive to bond interest rates (.02).

### Municipal Investment

Some states pay an additional 10 or 15 percent of the total investment, thus reducing local expenditures even further. This additional portion may come out of annual tax revenues or it may be bonded. If the source is tax revenues, then only 10% to 15% need be financed through bonds. However, changes in saving resulting from different state supplements are almost negligible.

### Total Investment

Total investment was increased and decreased by 10% and 20% with a resulting change in savings of ± 1% and ±2% respectively. This is encouraging in that the study conclusions are relatively unchanged by any systematic bias in estimating treatment costs.

### Annual Investment/O&M Cost

This nominal ratio was varied ±10% with no significant change in savings.

### Interceptor Cost/Treatment Cost

This ratio was varied by ± 10% and ±20% with resulting saving changes of ±1% and ±2% respectively. Obviously as the ratio increases, the regional alternative becomes less attractive. The sensitivities ranged from .42 to .48, establishing this parameter as important as the discount rate and the inflation rate.

Best Available Treatment (BAT)

BAT levels are not presently defined for municipal wastewater facilities. In either scenario selected, all 1983 discharges will be municipal. However, it is not difficult to determine that the impact will be small and should only affect Scenario V. In Scenario IX, treatment required for $BOD_5$ and $NH_3$-N greatly surpass any proposed draft guideline that has been presented for effluent limits for municipal treatment and, therefore, no additional cost would be incurred. Under Scenario V, major facilities will probably treat wastes sufficiently; several smaller facilities might require upgrading, but the total cost to upgrade would not increase more than 3%. Therefore, it is concluded the effects of BAT in this case study are minimal.

## H. CONCLUSIONS

Nine scenarios were originally selected for investigation in the Meramec case study. After developing a summary of costs for each, all but two were eliminated. Scenario V represents the least expensive solution which meets the July 1977 federal deadline for insuring water quality standards. Scenario IX represents the least cost solution and the expansive regional system defined in this scenario would require a three year delay in implementation until 1980. These scenarios most exemplified the issues being investigated in this report.

Detailed analysis of water quality was completed. There are additional short term risks in the delay period under Scenario IX. However, the long term benefits of Scenario IX are great and combined with the substantial savings, makes it the most attractive under the assumed nominal conditions.

Of these nine parameters analyzed in sensitivity studies, the most significant were the discount rate and short term and long term inflation rates. These terms can be combined to provide an estimate of real interest rates, for it is the difference between these rates which actually accounts for significant differences.

In conclusion, savings remain substantial under the variation of all parameters and in this case study it is recommended that a delay period be adopted and the complete regional system be selected for implementation.

## SECTION V

## CASE STUDY - THE CALUMET

### A. BASIN DESCRIPTION

The Grand Calumet River and Indiana Harbor Ship Canal is located in northwestern Indiana and flows primarily to Lake Michigan (see maps, Figures 18 and 19 ). The east branch of the river flows into the canal, while the west branch divides into two sections; one generally flowing east to join the east branch and the other flowing westward into Illinois. While climatic conditions on Lake Michigan influence the direction of flow and the point of equilibrium on the west branch, the culvert system on the west branch is the dominant factor in determining flow.

The Indiana Harbor Ship Canal is dredged to an approximate depth of twenty-four feet to Columbus Drive on the mainstem and past Indianapolis Boulevard on the Lake George Branch. The flow through the canal is complex and occasionally reverses in direction for short periods of time.

The flow in the system consists primarily of wastewater discharges from major municipal and industrial point sources. The cities of Gary, Hammond and East Chicago release approximately 110 million gallons of wastewater to the river each day.

Eight industries presently discharge through fifty-six existing pipes to either the canal, the harbor or the river. The major portion of the flow (1,755 MGD) is from the three major steel industries; U.S. Steel, Youngstown Sheet and Tube Company, and Inland Steel Company. ARCO and E.I. duPont also have significant discharges while U.S.S. Lead Refineries, Union Carbide and American Steel release minor volumes of wastewater.

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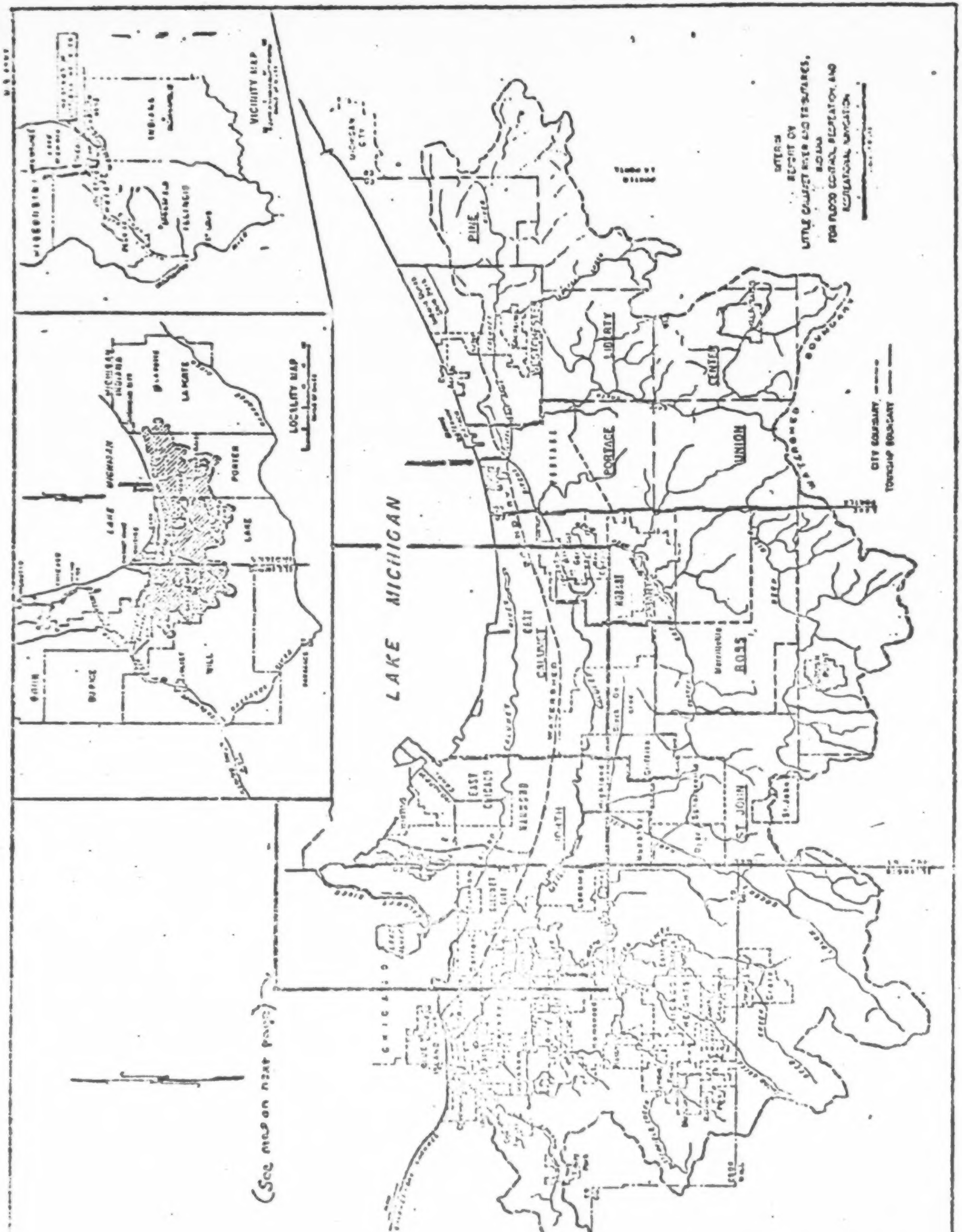
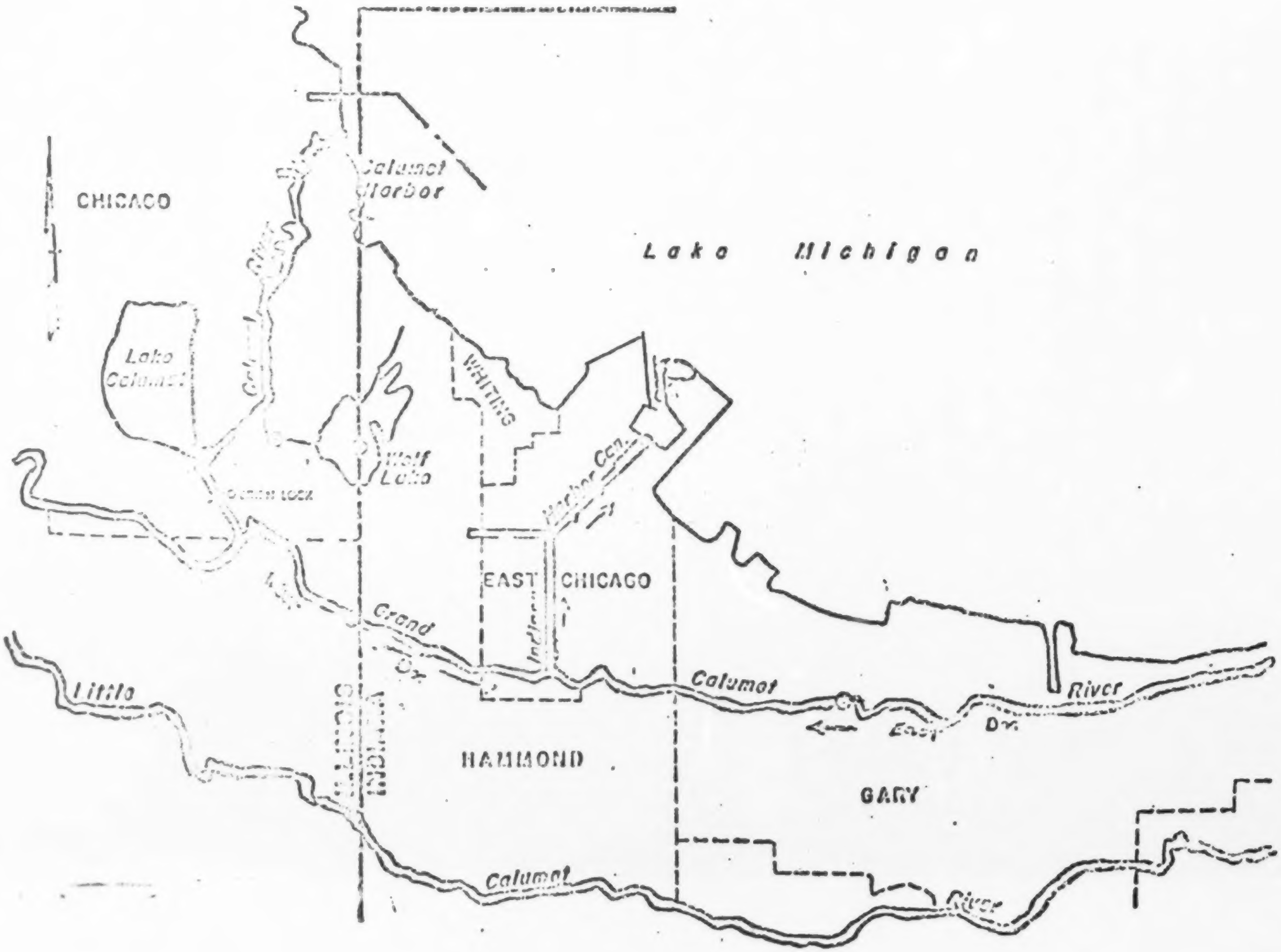
## FIGURE 18

## GRAND CALUMET RIVER AND INDIANA HARBOR SHIP CANAL



(See map on next page)

## FIGURE 19
## GRAND CALUMET RIVER AND INDIANA HARBOR SHIP CANAL
## DETAIL MAP



The three major steel plants are located in the Calumet Basin and account for nearly 14% of the total U.S. coke and iron production and almost 10% of the total U.S. steel production. Thus this small basin is unusual in that it has a particularly high concentration of coke/iron/steel production facilities.

The population in the Gary-Hammond-East Chicago SMSA was approximately 633,000 in 1970. During the 10 year period from 1960 to 1970, the population increase was only 10% with a natural increase of 85,000, and an out-migration of 26,000. This slight increase was an abrupt change from the trends of the 1950-1960 decade when the population increase was 40.5%.

The Bureau of Census has projected a population increase of approximately 12.5% for the state of Indiana, however there is concern that even this projection may turn out to be considerably higher than the actual.

For the Calumet Basin the population outlook is at best a bit damped in comparison to the State picture. Net out-migration may continue to increase due to continued decreases in the area businesses, and over the short run, through 1980, any natural population increase will probably be greatly offset by out-migration. While population is expected to increase, no problems should occur since municipal plants appear to have adequately anticipated the area's growth potential. However, this condition could drastically change given major changes in the area's economic condition.

Industrial and Municipal Discharger Inventory

The major municipal dischargers are East Chicago (14 MGD), Gary (53 MGD), and Hammond (41 MGD), with each providing secondary treatment.

Eight industries presently have continuous discharges to the water system. ARCO, U.S.S. Lead Refineries, Union Carbide Linde Division, and American Steel Foundries discharge from a single point, while other industries, E.I. duPont (9), Inland (16), U.S. Steel (16) and Youngstown (11) require multiple dischargers.

A complete inventory of each discharger is included in the Appendix.

Table 18 lists the major discharges to the system, their average flows, and lists the principal problem effluents. Since integrated steel mills generate much of the waste loads, a short discussion of the major steel making discharges follows.

Integrated Steel Mill Effluents

An integrated steel mill is a complex combination of interdependent operations involving five distinct manufacturing processes: (1) coke manufacturing, (2) iron manufacturing (3) steel manufacturing, (4) hot forming, and (5) cold finishing. Each of these processes has its own distinct set of wastewater effluents. Brief descriptions of each process and its major effluents are provided below.

Coke Manufacturing -

This is the first step necessary to convert iron ore to steel. With this process, coal is converted to pure carbon coke which is subsequently combined with iron ore and limestone in a blast furnace to produce iron.

The principal problem effluents for this process are: suspended solids, ammonia, phenols, cyanides and BOD.

## TABLE 18

## CALUMET DISCHARGERS

| Discharger | Type | Average Flow (MGD) | Principal Problem Effluents* |
|---|---|---|---|
| U.S. Steel | Integrated Steel Mill | 500.0 | See discussion in text |
| E.I.duPont | Inorganic Chemical Production | 14.0 | ammonia, chlorides, suspended solids, fluoride, sulfate, phosphates |
| ARCO | Petroleum Refining | 5.0 | ammonia, suspended solids, chlorides, phenols, sulfates, phosphates |
| U.S.S. Refinery | Lead Refining | .4 | chlorides, fluorides, sulfates |
| Union Carbide | Industrial Gas Production | .1 | phosphates |
| American Steel Foundries | Steel Foundry | .2 | chlorides, phosphates |
| Inland Steel | Integrated Steel Mill | 977.0 | See discussion in text |
| Youngstown Steel | Integrated Steel Mill | 224.0 | See discussion in text |
| Gary | Municipal Wastes | 53.0 | $BOD_5$, suspended solids, phosphates, sulfates, chlorides, ammonia |
| Hammond | Municipal Wastes | 41.0 | $BOD_5$, suspended solids, phosphates, sulfates, chlorides, ammonia |
| East Chicago | Municipal Wastes | 14.0 | $BOD_5$, suspended solids, phosphates, sulfates, chlorides, ammonia |

*Principal Problem Effluents=those effluents whose average concentrations are at or below water quality standards.

Some of the coke plant wastes from the Youngstown and Inland Steel plants are treated at the East Chicago municipal waste water treatment plant. This practice at present significantly degrades the performance of this municipal plant. Therefore pretreatment of these coke wastes is necessary before transfer to East Chicago for further treatment.

### Iron Manufacturing -

In the second step of the steel making process, iron ore is converted to iron which is then used as a principal feedstock for the steel making process.

The principal problem effluents are: suspended solids, phenols, cyanides, and ammonia.

### Steel Manufacturing -

At this step the iron is further refined to form steel in either a basic oxygen, open hearth, or electric arc furnace.

Principal problem effluents are suspended solids and fluorides.

### Hot Forming -

This is a steel finishing process in which steel ingots are reheated and formed into various shapes. Some of these are end products of the steel mill, while others require further finishing operations.

### Cold Finishing -

Cold finishing operations impart desirable surfaces or shapes or mechanical characteristics to the hot rolled products. Major subprocesses in this category include pickling, plating, galvanizing, and cold rolling and shaping.

Principal problem effluents are sulfates, phenols, BOD, heavy metals, chlorides, oil, suspended solids and fluorides.

## B. EXISTENT WATER QUALITY

The overall basin water quality is poor. Water quality data is being collected and analyzed by the State of Indiana at eight sampling stations in the river/canal system. Stream flow records are available for the Years 1972 and 1973 and are shown in the Table 19. During this period phosphates were significantly reduced as a result of a state-wide ban. One section of the canal exhibited reductions in suspended solids, BOD, ammonia, phenols and iron.

Water quality standards are not being maintained in most sections of the system. Dissolved oxygen is a problem in the west branch of the river and the dredged portion in the canal including the Lake George Branch. BOD is high at all stations, and concentrations found in the west branch are much higher. Ammonia is a wide spread problem, but again, the primary area of concern is the west branch. Temperature violations have consistently occurred during October and early November at all stations except IHC 0 which is the one closest to Lake Michigan. Phosphorus limits, even after the ban, are violated at all stations, with primary loads concentrated at the municipal wastewater treatment facilities and ARCO's discharge. While fecal coliform standards are violated at all sampling stations, the major problem area is the west branch whose flow consists entirely of municipal treatment facility effluents. Occasionally fluoride concentrations exceed standards at the Indianapolis Boulevard Station on the west branch of the river.

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## TABLE 19

## IN STREAM WATER QUALITY

NOTE: 1973 Data based on sampling completed by 9/73.

| Description | Flow | | | Summer Temperature | | | D. O. | | | $BOD_5$ | | | $NH_3$ | | | $NO_3$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Quality Standard | cfs. | | | 32.1°C April - September | | | Ave. 3.0 mg/1 Min. 2.0 mg/1 | | | 10 mg/1 | | | 1.5 mg/1 | | | No Standard | | |
| Monitoring Stations | Ave. 72 | Ave. 73 | Tot. 72-73 Min. | 72 Ave. | 73 Ave. | 72-73 Max. | 72 Ave. | 73 Ave. | 73-72 Min. | 72 Ave. | 73 Ave. | 72-73 Max. | 72 Ave. | 73 Ave. | 72-73 Max. | 72 Ave. | 73 Ave. | 72-73 Max. |
| GCR 41 Grand Calumet River Gary (U.S. 12) | [illegible] | [illegible] | 650 | 22.7 | 21.4 | 27 | 7.8 | 7.9 | 5.8 | 4.4 | 3.6 | 15.0 | 1.9 | 1.8 | 5.6 | 0.7 | 0.5 | 2.7 |
| GCR 37 Grand Calumet River East Chicago (Kennedy Rd.) | 835 | 835 | 600 | 23.1 | 20.9 | 23 | 6.8 | 6.9 | 3.9 | 4.7 | 3.9 | 16.0 | 2.3 | 2.35 | 5.70 | 0.5 | 0.5 | 1.1 |
| GCR 36 Grand Calumet River East Chicago (Indy. Blvd.) | 16 (east) | 16 (east) | 0 | 20.7 | 20.4 | 23 | 4.2 | 4.4 | 0.3 | 33.3 | 32.4 | 20.0 | - | 44.8 | 86 | 0.2 | 0.2 | 0.5 |
| GCR 34 Grand Calumet River Hammond (U.S. 12) | 46 (west) | 46 (west) | 30 | 19.0 | 19.4 | 27 | 4.5 | 3.7 | 1.1 | 21.7 | 17.0 | 32.0 | - | 15.0 | 36.0 | 0.3 | 0.9 | 4.4 |
| IHC 3W Indiana Harbor Canal East Chicago (Indy. Blvd.) | 174 | 174 | 0 | 23.3 | 20.3 | 23 | 2.7 | 4.8 | 0.3 | 6.2 | 4.2 | 14.0 | 5.1 | 4.1 | 9.0 | 0.4 | 0.6 | 1.9 |
| IHC 3S Indiana Harbor Canal East Chicago (Columbus Drive) | 901 | 901 | 623 | 22.3 | 20.9 | 23 | 6.0 | 5.8 | 3.4 | 5.9 | 3.5 | 19.0 | 3.4 | 3.24 | 8.5 | 0.6 | 0.5 | 1.3 |
| IHC 1 Indiana Harbor Canal East Chicago (Dickey Rd.) | 927 | 927 | 0 | 22.6 | 22.8 | 27 | 4.4 | 4.3 | 1.6 | 5.1 | 3.4 | 12.0 | 4.7 | 3.3 | 8.5 | 0.6 | 0.5 | 1.1 |
| IHC 0 Indiana Harbor Canal East Chicago (Youngstown Steel) | 1407 | 1407 | 0 | - | 21.2 | 24 | - | 5.8 | 3.7 | - | 2.4 | 3.5 | - | 2.3 | 6.3 | - | 0.6 | 2.3 |

## TABLE 19 (continued)
## IN STREAM WATER QUALITY

| Description | Fecal Coliform | | | Winter Temperature | | | Total Phosphorus | | | Suspended Solids | | | pH | | | Fluorides | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Quality Standard | Geometric Mean 1000/100 ml Except During Storm Runoff | | | 15.6°C October - March | | | .10 mg/1 | | | No Standard | | | 6.5 to 8.5 | | | 1.3 mg/1 | | |
| Monitoring Stations | 72 Ave. | 73 Ave. | 72-73 Max. | 72 Ave. | 73 Ave. | 72-73 Max. | 72 Ave. | 73 Ave. | 72-73 Max. | 72 Ave. | 73 Ave. | 72-73 Max. | 72 Ave. | 73 Ave. | 72-73 Max. (Min.) | 72 Ave. | 73 Ave. | 72-73 Max. |
| GCR 41 Grand Calumet River Gary (U.S. 12) | 6733 | 1061 | 39000 | 11.5 | 15.6 | 22 | 1.4 | .10* | 6.6 | 18 | 17 | 50 | 7.0 | 7.0 | 7.9<br>(6.3) | - | .8 | 1.1 |
| GCR 37 Grand Calumet River East Chicago (Kennedy Rd.) | 3919 | 1340 | 33000 | 12.6 | 14.6 | 22 | 1.1 | .23 | 2.7 | 17 | 18 | 47 | 7.1 | 7.2 | 7.8<br>(6.5) | - | .7 | 1.1 |
| GCR 36 Grand Calumet River East Chicago (Indy. Blvd.) | 306171 | 64665 | 1300000 | 10.9 | 12.2 | 21 | 4.5 | .85 | 9.9 | 30 | 22 | 60 | 7.4 | 7.3 | 8.3<br>(6.8) | - | 1.2 | 1.5 |
| GCR 34 Grand Calumet River Hammond (U.S. 12) | 619242 | 43189 | 3300000 | 10.4 | 10.0 | 18 | 8.5 | 1.84 | 9.9 | 41 | 20 | 130 | 7.1 | 7.1 | 7.7<br>(6.6) | .8 | .7 | 1.1 |
| IHC 3M Indiana Harbor Canal East Chicago (Indy. Blvd.) | 2552 | 1138 | 16000 | 12.5 | 17.0 | 25 | 1.2 | .19 | 3.3 | 15 | 10.6 | 31 | 7.1 | 7.1 | 7.8<br>(6.5) | - | .7 | .9 |
| IHC 33 Indiana Harbor Canal East Chicago (Columbia Drive) | 4050 | 4160 | 30000 | 12.1 | 13.6 | 22 | 1.1 | .23 | 2.5 | 16 | 11.9 | 30 | 7.1 | 7.2 | 7.7<br>(6.6) | - | .6 | 1.0 |
| IHC 1 Indiana Harbor Canal East Chicago (Dickey Rd.) | 26058 | 1293 | 63000 | 11.1 | 13.0 | 17 | 1.0 | .13 | 1.6 | 19 | 14.1 | 70 | 7.1 | 7.1 | 7.7<br>(6.4) | .7 | .6 | .9 |
| IHC 0 Indiana Harbor Canal East Chicago (Youngstown Steel) | - | 971 | 2300 | - | 12.5 | 15 | - | .10 | .16 | - | 8.2 | 16 | - | 7.3 | 7.9<br>(6.8) | - | .5 | .7 |

*Value obtained 9/11/73 not included - apparently incorrect.

## TABLE 19 (concluded)

## IN STREAM WATER QUALITY

| Description | Phenols | | | Cyanides | | | Iron | | | Sulfates | | | Chlorides | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Quality Standard | .010 mg/1 | | | .100 mg/1 | | | No Standard | | | 75 mg/1 | | | 35 mg/1 except river flow to Ill. = 125 mg/1 | | |
| Monitoring Stations | 72 Avg. | 73 Avg. | 72-73 Max. | 72 Avg. | 73 Avg. | 72-73 Max. | 72 Avg. | 73 Avg. | 72-73 Max. | 72 Avg. | 73 Avg. | 72-73 Max. | 72 Avg. | 73 Avg. | 72-73 Max. |
| GCR 41 Grand Calumet River Gary (U.S. 12) | - | .031 | .066 | - | .707 | 1.500 | - | 1.5 | 2.3 | - | 44.0 | 60.0 | 27 | 22 | 44 |
| GCR 37 Grand Calumet River East Chicago (Kennedy Av.) | - | .013 | .053 | - | .505 | 1.000 | - | 1.53 | 3.0 | - | 53.1 | 115.0 | 31 | 30.6 | [illegible] |
| GCR 35 Grand Calumet River East Chicago (Indy. Blvd.) | - | .501 | 1.000 | - | .176 | .344 | - | 1.5 | 2.6 | - | 137.8 | 410.0 | 201 | 250.2 | 520 |
| GCR 34 Grand Calumet River Hammond (U.S. 12) | .022 | .011 | .056 | .005 | .061 | .230 | 1.4 | 1.2 | 3.1 | 147.3 | 133.9 | 223.0 | 155 | 129.5 | 550 |
| IHC 3W Indiana Harbor Canal East Chicago (Indy. Blvd.) | - | .005 | .013 | - | .123 | .350 | - | 1.07 | 1.8 | - | 86.7 | 223.0 | 53 | 59.7 | 125 |
| IHC 2S Indiana Harbor Canal East Chicago (Columbia Drive) | - | .019 | .066 | - | .134 | .095 | - | 1.3 | 2.0 | - | 50.3 | 70.0 | 40 | 33.3 | 125 |
| IHC 1 Indiana Harbor Canal East Chicago (Dickey Rd.) | .023 | .004 | .170 | .127 | .196 | .350 | 7.2 | 1.3 | 4.5 | 55.1 | 59.7 | 80.0 | 40 | 34.3 | 125 |
| IHC D Indiana Harbor Canal East Chicago (Youngstown Steel) | - | .003 | .017 | - | .172 | .460 | - | .6 | 1.1 | - | 43.6 | 70.0 | - | 25.6 | 37 |

Source: Combinatorics, Inc., (A Subsidiary of MATHEMATICA, INC.), Load Allocation Study of the Grand Calumet River and Indiana Harbor Ship Canal, Lafayette, Indiana, 1/74.

While phenol violations occur most frequently in the west branch, phenol is a problem throughout the system. However, instream phenol concentrations approached the standard of .010 mg/l at station IHC-3W on the Lake George Branch, the lower part of the canal and in the river as it flows into Illinois.

Cyanides are a major problem in the east branch of the river. As the river flows toward the lake, cyanide concentrations are reduced, however, the average recorded value at the station closest to the lake is almost twice the standard. Only in the section of the river that flows into Illinois are average cyanides concentrations acceptable.

There is no standard for total iron but a maximum concentration of .3 mg/l of dissolved iron is used as a standard. A present, no data exists for dissolved iron and it is recommended that iron concentrations be monitored.

Sulfate concentrations meet standards in the upper east branch and the mainstem of the canal, with standards violated only in the four remaining stations. Chloride concentrations exceed the standard at all stations but three stations (GCR37, GCR41, and IHCO) only record violations in the winter months indicating a definite impact of the road salting program.

Flow conditions in the Grand Calumet River are somewhat peculiar in that flow reversals occur in the west branch of the river and the canal from time to time. These reversals are caused by strong winds or rising lake levels, and are expected to occur frequently in the winter and spring.

Another condition which sometimes occurs is the loss of flow into marsh areas in the east branch of the Grand Calument River. This was exhibited in the flow survey of the river and canal system in October of 1973. The results of this flow survey taken by Combinatorics (Reference 10) are shown in Figure 20 and Table 20.

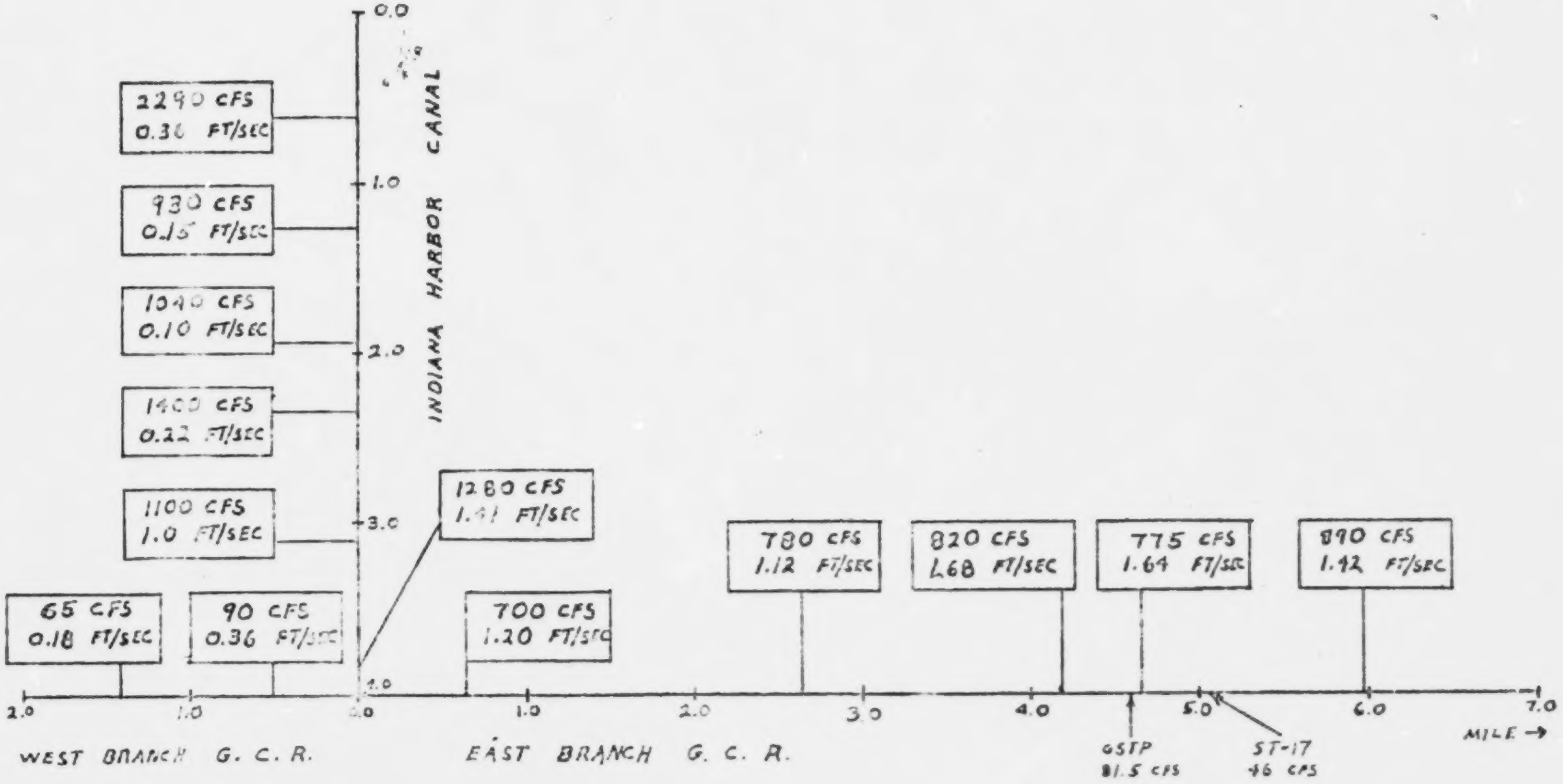
## C. ALTERNATIVE TREATMENT PLANS

The FWPCAA of 1972 requires that all private dischargers shall implement BPT by 1977, and that all publicly owned dischargers must treat to a secondary level by that same date. If these levels of treatment are insufficient to insure that water quality standards are met, then loads must be allocated to assure that standards are met. For the Calumet River and Harbor Canal System, application of BPT satisfies all water quality standards with the exception of ammonia, phenols, BOD, phosphate, sulfate, and chloride constituents.

Sulfate and chloride treatment is very expensive, and a major source of chloride is the winter road salting program which accounts for almost one-half the chloride load to Lake Michigan from the canal. Other prime sources of chlorides and sulfates are the three municipal plants. The cost and environmental impact of chloride and sulfate treatment is great, and the recommended process for meeting Lake standards was to divert the west branch of the Grand Calumet westward into Illinois through the use of a dam and to treat at a few selected outlets. This would eliminate a large portion of the sulfate and chloride total load to Lake Michigan. Therefore, the costs of treating sulfates and chlorides were not considered in this case study. However, diversion costs were estimated along with load reductions to Lake Michigan as a special case sensitivity study.

FIGURE 20

FLOW SURVEY OCTOBER 1-4, 1973



Source: Combinatorics, Inc., (A Subsidiary of MATHEMATICA, INC.), Load Allocation Study of the Lower Meramec River Basin, Lafayette, Indiana, June, 1974.

TABLE 20

HISTORICAL DATA FLOW

| DATE | East Branch, Grand Calument River | | Indiana Harbor Ship Canal | |
|---|---|---|---|---|
| | Mile 4.47 U.S. Highway 12 Flow [cfs] | Mile .66 Kennedy Ave. Flow [cfs] | Mile 3.78 151st Street Flow [cfs] | Mile 1.22 Dickey Road Flow [cfs] |
| November, 1954 | --- | 870 | 785 | --- |
| May, 1955 | 725 | 726 | 657 | --- |
| August, 1955 | 810 | 1,010 | 977 | --- |
| September, 1955 | 824 | 844 | 933 | 1,040 |
| March, 1956 | 722 | 806 | 855 | 1,128 |
| March, 195[illegible] | 718 | 894 | 1,010 | 1,450 |

Source: U.S. Geological Survey gage records.

Even excluding sulfate and chloride violations, water quality standards for ammonia, phenols, BOD, and phosphates must be met, and a load allocation is necessary to meet state water standards. The actual load allocation study prepared by Combinatorics (Reference 10) was utilized in this analysis. This allocation for 1977 requires phenol treatment to the level of Best Available Technology (BAT) while ammonia removals are closer to BPT levels. Major BOD, phosphate and ammonia reductions are required at the municipal plants and advanced wastewater treatment (AWT) facilities are to be constructed to meet the allocated discharge levels. Each municipal treatment plant is already operating at a secondary treatment level. In addition pre-treatment of coke plant ammonia wastes from Youngstown and Inland Steel companies will be upgraded prior to delivery to East Chicago. These industrial wastes, particularly ammonia, have had a very detrimental effect on East Chicago's treatment.

For the Calumet system, two detailed cases were analyzed to determine the relationship between total cost, water quality and the timing of investments. The first case complies with implementing the water quality standards by 1977 as required by the 1972 Amendments, while the second case complies with the same water quality standards in 1980. No major process changes were assumed, and recycling of effluents was applied as specified in the EPA Development Document (Reference 45).

Two additional cases were also considered to ascertain their effect on the conclusions reached for the 1977 and 1980 BPT cases. The first of these is the application of BAT to the industrial effluents as required by FWPCAA of 1972. However, municipal BAT is not considered, since the effluent guidelines for these sources have not yet been defined.

The second case consists of a diversion scheme whereby a dam would be used to divert the west branch of the Calumet westward into Illinois and then to the Mississippi River.

These cases will not be evaluated to the level of detail of the two BPT cases, and are considered in sensitivity studies.

## D. COST DATA

Costs for both 1977 and 1980 compliance were estimated using the methodology previously described. Costs were developed for each outlet and then summed to estimate total company and municipality costs.

In order to meet water quality standards, the steel industry must treat phenols to BAT effluent levels, and municipalities must utilize advanced waste treatement trains. The cost estimate for both cases are significantly higher than costs required for BPT and secondary treatment.

Table 21 itemizes total investment and annual operating and maintenance costs calculated for each outlet in 1974 dollars.

The operating and maintenance cost includes sludge disposal, chemical energy and power, and carbon column rental (where applicable for dephenolization) costs.

The discharge costs are totaled below:

- Private Treatment Investments $116.1 million
- Annual Operation & Maintenance $12.5 million
- Municipal Discharge Investment $70.7 million
- Annual Operation & Maintenance $6.56 million

## TABLE 21

## BPT TREATMENT COSTS BY DISCHARGE
(1974 dollars)

| Discharger I.D. | Investment | Operation & Maintenance |
|---|---|---|
| U.S. Steel | | |
| GW-1 | 69,000 | 31,000 |
| GW-2 | 5,182,000 | 1,033,000 |
| GW-3 | 287,000 | 119,000 |
| GW-5 (+2A,3A) | 36,980,000 | 3,639,000 |
| GW-6 | 215,000 | 23,000 |
| GW-7 | 3,507,000 | 214,000 |
| GW-7A | 7,430,000 | 1,390,000 |
| ST-17 | 3,675,000 | 664,000 |
| GW-9 | 9,512,000 | 505,000 |
| GW-10A | 3,275,000 | 319,000 |
| GW-11A | 3,106,000 | 289,000 |
| GW-4 | -- | -- |
| GW-13 | -- | -- |
| ST-14 | -- | -- |
| Inland Steel | | |
| 4E-1 | 10,921,000 | 613,000 |
| 5E-2 (+5E1,5E3) | 1,035,000 | 71,000 |
| 7E-1 | 705,000 | 40,000 |
| 136-1 + 13H-1 | 6,287,000 | 588,000 |
| 14H-TT | 781,000 | 294,000 |
| 15H-TT | 781,000 | 295,000 |
| 16H-3 | 4,106,000 | 63,000 |
| 16F-1 | 414,000 | 64,000 |
| IE-2;6E-1 | -- | -- |
| 10E-1 | -- | -- |
| 16H-1 | -- | -- |
| 16H-2 | -- | -- |

## TABLE 21 (concluded)

## BPT TREATMENT COSTS BY DISCHARGE

(1974 dollars)

| Discharger I.D. | Investment | Operation & Maintenance |
|---|---|---|
| Youngstown | | |
| YS-12 (13+22) | 6,034,000 | 1,091,000 |
| YS-15 | 2,854,000 | 138,000 |
| YS-18A | 4,503,000 | 403,000 |
| YS-20 | 364,000 | 24,000 |
| YS-2 | -- | -- |
| YS-4 | -- | -- |
| YS-8 | -- | -- |
| YS-11 | -- | -- |
| YS-13 | -- | -- |
| YS-14 | -- | -- |
| ARCO | 1,824,000 | 104,000 |
| DuPont | 2,287,000 | 363,000 |
| Gary STP | 35,870,000 | 2,916,000 |
| Hammond STP | 13,997,000 | 1,901,000 |
| East Chicago STP | 20,880,000 | 1,750,000 |

Source: Combinatorics, Inc., (A Subsidiary of MATHEMATICA, INC.), Load Allocation Study of the Grand Calumet River and Indiana Harbor Ship Canal, Lafayette, Indiana, January, 1974.

The above information is used to determine the cash flow and total life cycle costs required for both 1977 and 1980 compliance dates. The results are discussed later. However, total investment cost for 1977 compliance is $188.1 million, while 1980 compliance costs $186.6 million resulting in a saving of less than 1%. Life cycle costs for 1977 and 1980 are $475.5 million and $474.0 million respectively. Again, total life cycle costs decrease by less than 1%.

The industrial and muncipal costs listed above are generated using standard interest models and historic inflation rates. Price increases due to increases in construction costs resulting from environmental stimulated demands were based on Reference 37.

Financing of private investments is assumed to be divided over a three year period, with 10%, 40% and 50% required the first, second and third year of construction. Federal financing for up to 75% of total public investment is available and consequently it was assumed that municipalities only finance 25% of the total investment. This investment is made in the compliance target year.

The life cycle cost estimates are estimated by summing all annual investment and O&M costs over the 24 year assumed life of the facilities. These totals are then discounted back to 1974 for comparison purposes.

The various economic parameters used in the cost evaluation to determine total dollar value for the 1977 and 1980 nominal cases are listed in Table 22.

## TABLE 22

## FINANCIAL PARAMETERS FOR COST EVALUATION

| Parameter | Value |
|---|---|
| Short Term Inflation | 8% per year |
| Long Term Inflation | 4% per year |
| Discount Rate | 8% per year |
| Interest Rate | 7% per year |
| Industrial Payback Period | 10 years |
| Municipal Payback Period | 20 years |
| Municipal Investment Percentage | 25% |

Source: MATHEMATICA, Inc.

## E. PROJECTED WATER QUALITY

Water quality projections for the Grand Calumet River Basin are generated by using the MULQUAL model with loads allocated to minimize total investment while meeting stream water quality standards. There is no difference between projected water quality for the 1977 or 1980 cases, since each case must meet the same standards.

A comparison of existing and projected water quality for the Harbor Canal and Grand Calumet River is shown in the Figures 21 through 25. Table 23 lists loads. As can be seen from the graphs, BOD, ammonia, phenol and cyanide concentrations are significantly reduced.

## F. RESULTS

The cost savings between complying in 1977 and delaying it for three years until 1980 is an insignificant amount. The economic benefit of the delay is approximately $1.5 million. However, the costs for the delay are three more years of existing heavy pollution loadings to Lake Michigan. The following Table 24 gives the total loadings to the Lake over the three year period.

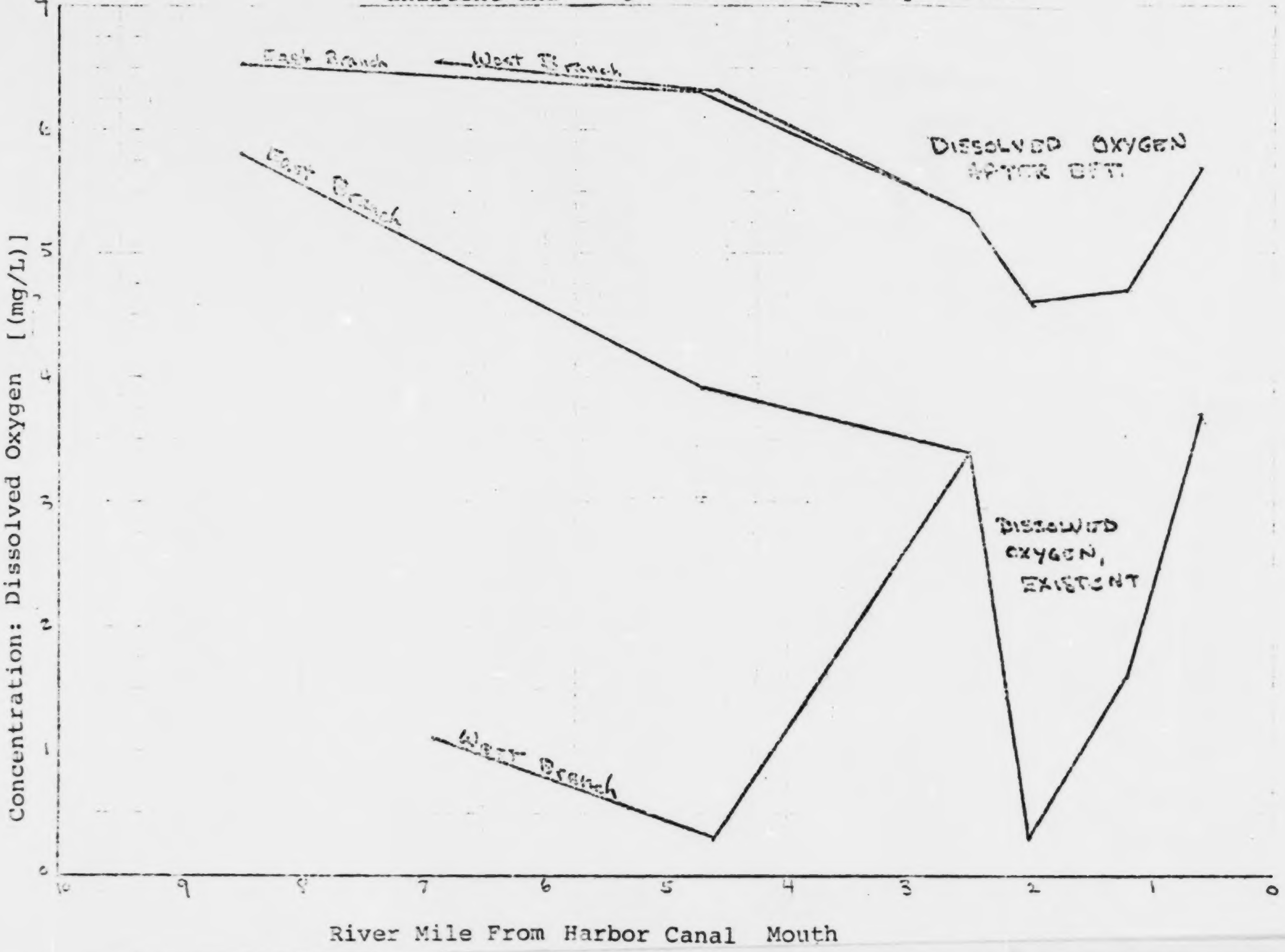
## G. SENSITIVITY STUDIES

Sensitivity studies were run to determine the effect of parameter variations on the computed cost savings. The parameters include: discount rate, short term inflation rate, long term inflation rate, amortization rate, municipal investment percentage, total investment, annual investment/O&M ratio, and the phasing of industrial investments. Table 25 summarizes the analysis.

The phasing of investment refers to the cost allocations for the three year construction period, and a phase scenario of 10%-20%-70% means that 10% of the investment is made the first year, 20% the second, and 70% the third year. This analysis was only applied to industrial costs.

Figure 21

Existent and Projected Water Quality - D.O.



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## FIGURE 22

Existent and Projected Water Quality Phenols

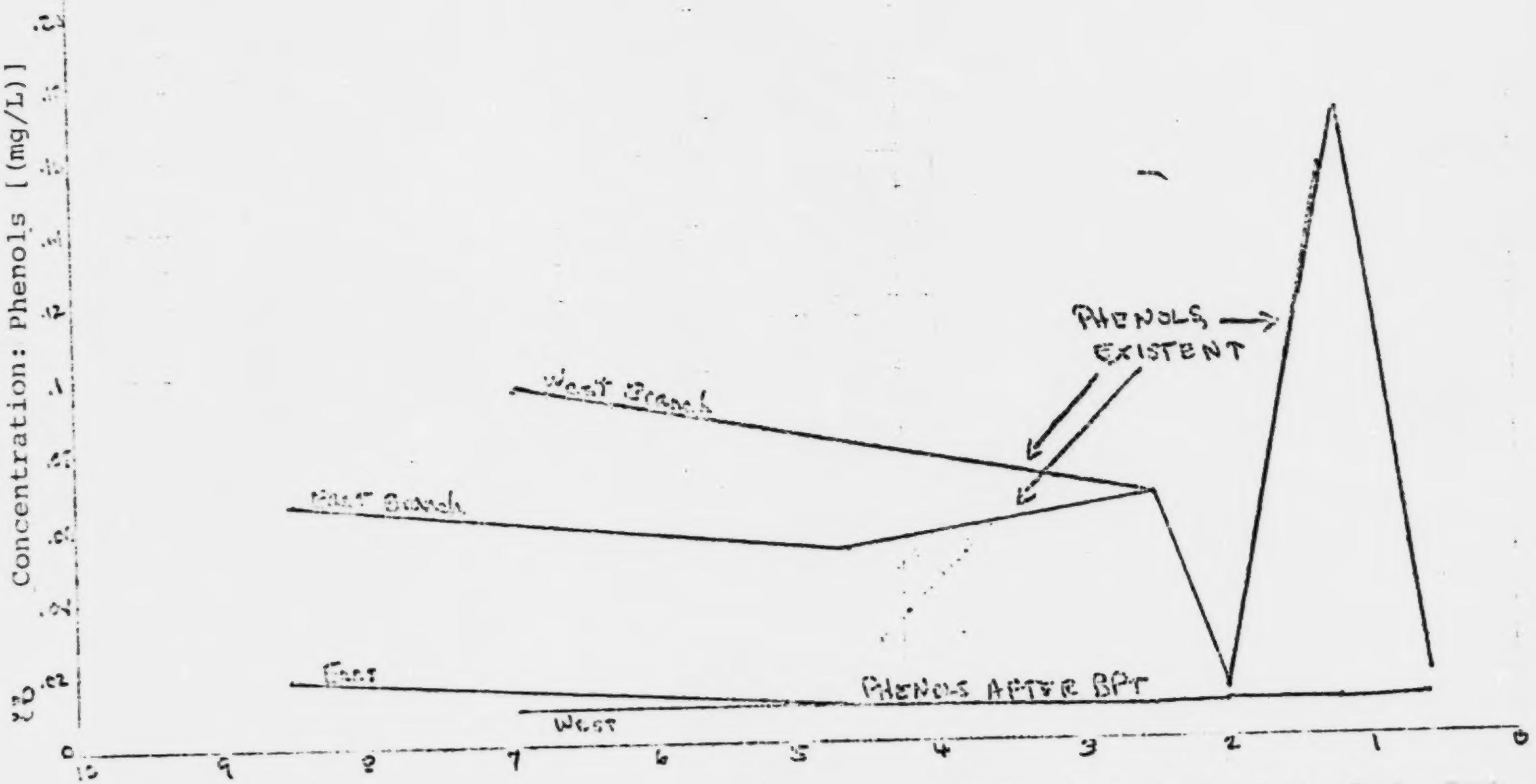

FIGURE 23

Existent and Projected Water Quality

AMMONIA

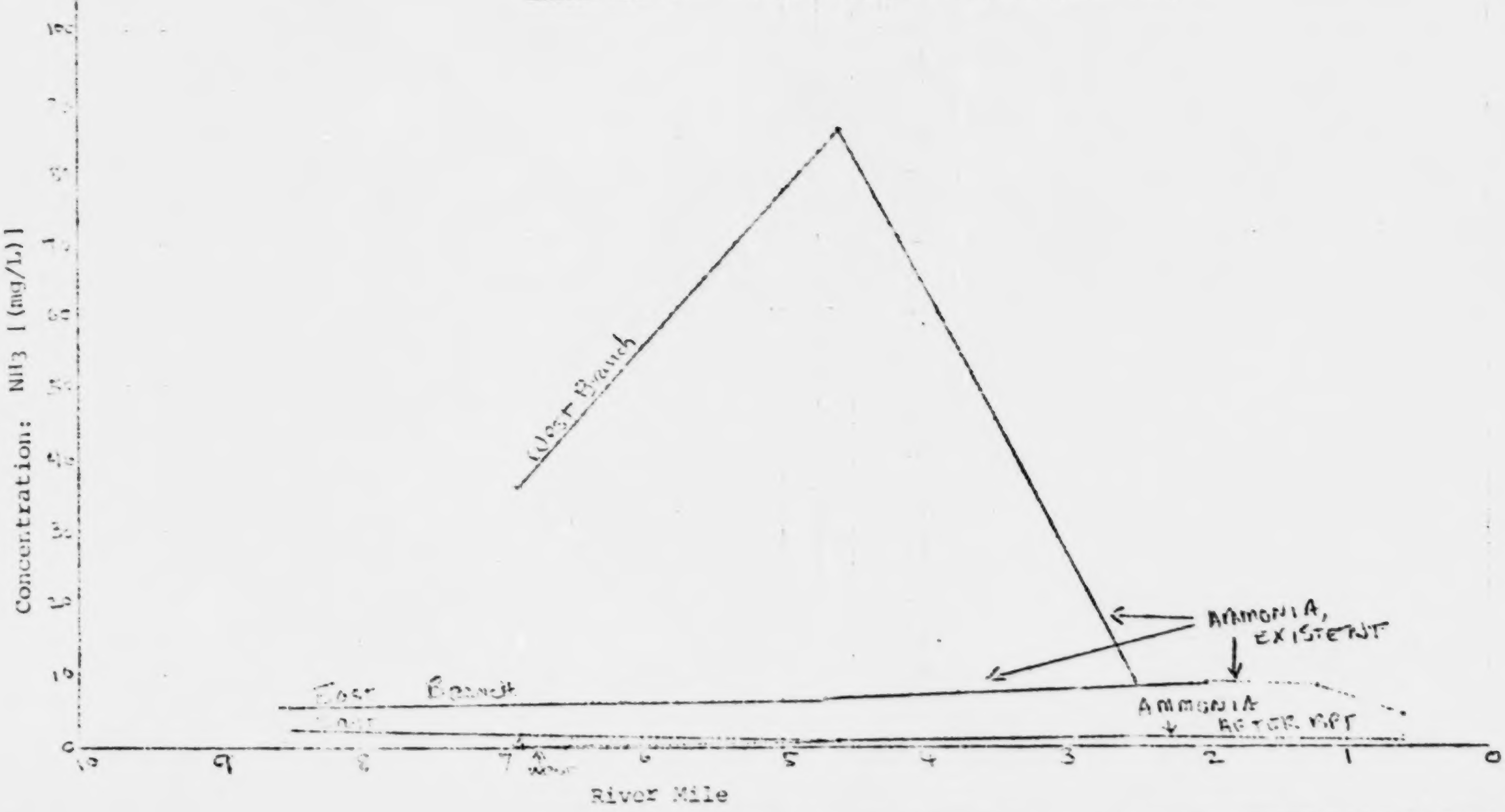

FIGURE 24

Existent and Projected Water Quality

CYANIDE

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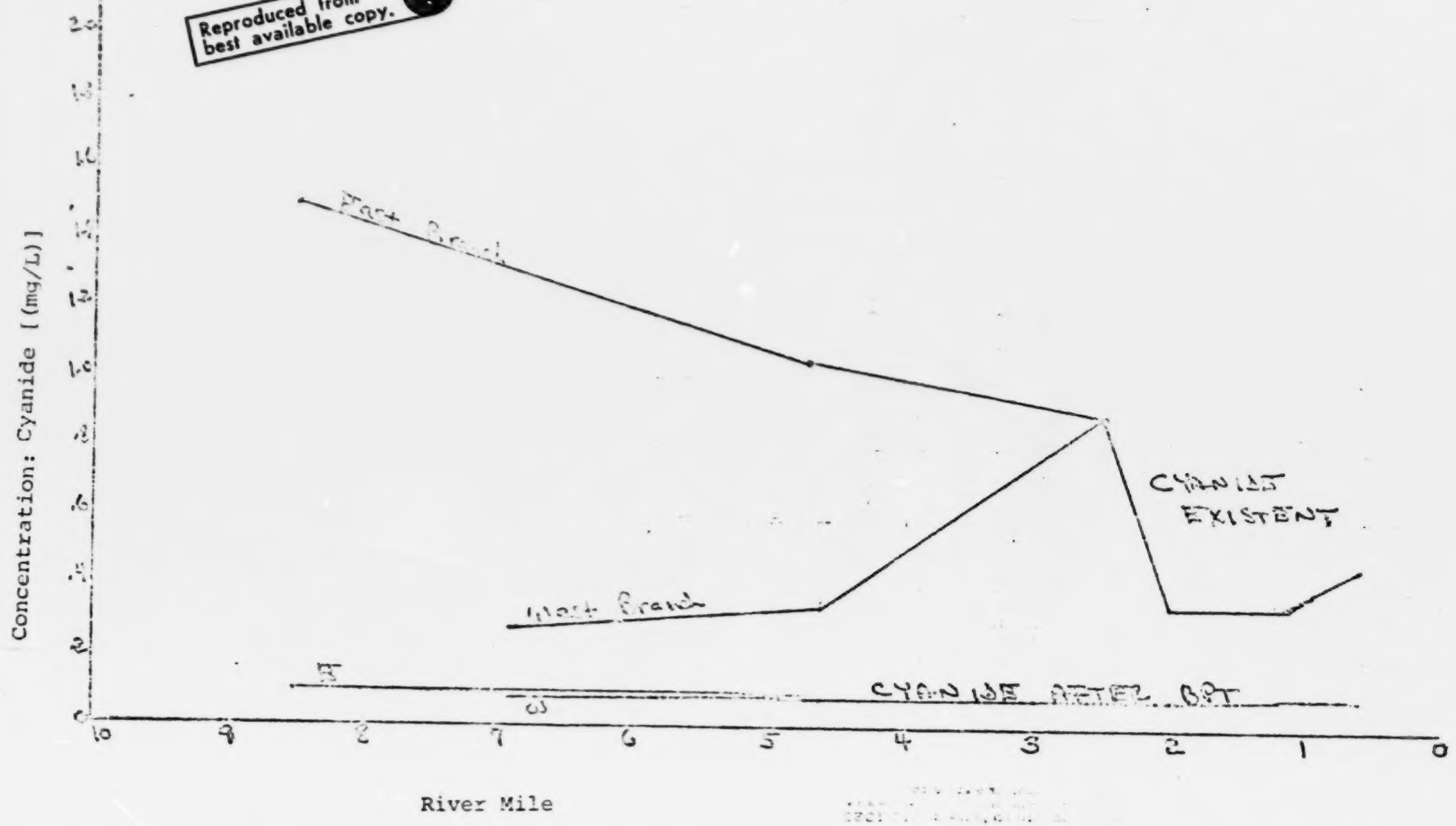
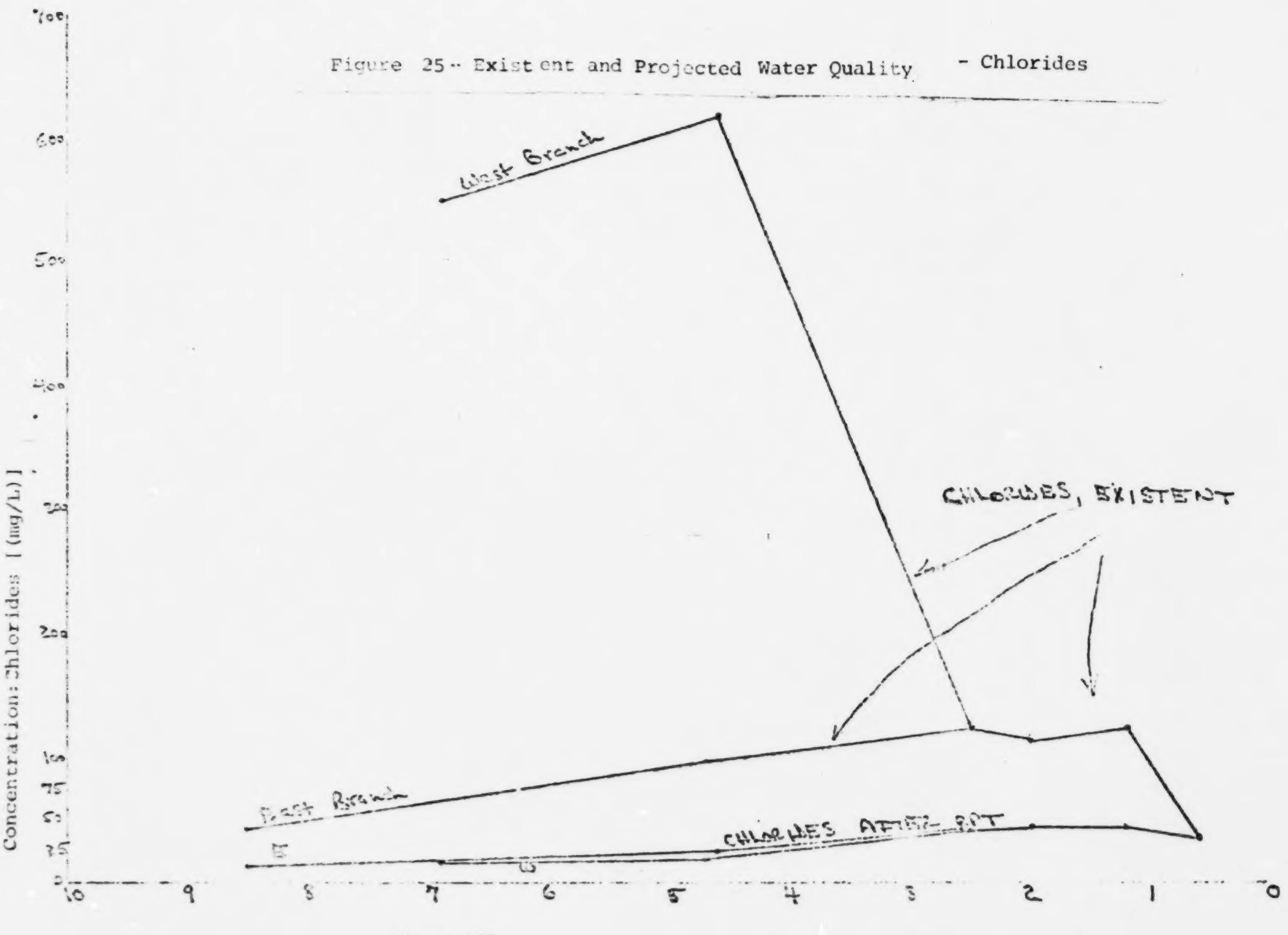


Figure 25 - Existent and Projected Water Quality - Chlorides



Source: MATHEMATICA, Inc.

## TABLE 23

## NET DISCHARGE LOADS *

| Outlet I.D. | 1977 BPT Allocations | | BAT Loadings | |
|---|---|---|---|---|
| U.S. Steel<br>GW-1 | Ammonia | 623. | Ammonia | 49.8 |
| | Cyanide | 3.26 | Cyanide | 0.033 |
| | Phenols | 4.47 | Phenols | 1.12 |
| | Suspended Solids | 146.0 | Suspended Solids | 29.2 |
| GW-2 | Ammonia | 354. | Ammonia | 28.3 |
| | Cyanide | 3.69 | Cyanide | 0.037 |
| | Phenols | 0.557 | Phenols | 0.14 |
| | Suspended Solids | 159. | Suspended Solids | 31.8 |
| GW-3 | Ammonia | 49.115 | Ammonia | 3.93 |
| | Cyanide | 4.30 | Cyanide | 0.043 |
| | Phenols | 0.130 | Phenols | 0.032 |
| | Suspended Solids | 87.6 | Suspended Solids | 17.5 |
| GW-5(+2A,3A) | Ammonia | 995. | Ammonia | 79.6 |
| | Cyanide | 94.85 | Cyanide | 1.61 |
| | Phenols | 3.25 | Phenols | 0.41 |
| | Suspended Solids | 1800.0 | Suspended Solids | 360.0 |
| GW6 | Suspended Solids | 1440. | Suspended Solids | 720.6 |
| GW-7 | Suspended Solids | 163. | Not Treated-Minimal Loads | |
| GW-7A | Phenols | 10.9 | | |
| | Suspended Solids | 7640.0 | Suspended Solids | 1530.0 |
| ST-17 | Suspended Solids | 4450.0 | Not Treated-Minimal Loads | |
| GW-9 | Suspended Solids | 110.0 | Not Treated-Minimal Loads | |
| GW-10A | Ammonia | 57.5 | Ammonia | 4.6 |
| | Cyanide | 14.4 | Cyanide | 2.41 |
| | Phenols | 1.1 | Phenols | 0.14 |
| | Suspended Solids | 3160. | Suspended Solids | 632. |

*Computed loads were derived in order to estimate costs as described in Section III.

TABLE 23 (continued)

| Outlet I.D. | 1977 BPT Allocations | | BAT Loadings | |
|---|---|---|---|---|
| U.S. Steel (Cont.) | | | | |
| GW-11A | Ammonia | 158.0 | Ammonia | 12.6 |
| | Cyanide | 39.4 | Cyanide | 6.58 |
| | Phenols | 1.58 | Phenols | 0.20 |
| | Suspended Solids | 8640. | Suspended Solids | 1730.5 |
| GW-4 | No Treatment Required | | No Treatment Required | |
| GW-13 | No Treatment Required | | No Treatment Required | |
| ST-14 | Suspended Solids | 813.0 | Suspended Solids | 163. |
| Inland | | | | |
| 4E-1 | Ammonia | 773.0 | Ammonia | 61.8 |
| | Cyanide | 20.0 | Cyanide | 0.34 |
| | Phenols | 8.65 | Phenols | 1.08 |
| | Suspended Solids | 120. | Suspended Solids | 23.9 |
| 5E-2(+5E-1, 5E-3) | Suspended Solids | 2410.0 | Suspended Solids | 483. |
| 7E-1(+6E-1 for BAT) | Ammonia | 35.9 | Ammonia | 2.87 |
| | Cyanide | 25.0 | Cyanide | 4.18 |
| | Phenols | 16.9 | Phenols | 2.12 |
| | Suspended Solids | 136. | Suspended Solids | 27.2 |
| 13G-1 | Ammonia | 146.4 | Ammonia | 11.7 |
| | Cyanide | 6.25 | Cyanide | 1.04 |
| | Phenols | 4.68 | Phenols | 0.58 |
| | Suspended Solids | 143.08 | Suspended Solids | 28.6 |
| 13H-1 | Ammonia | 449. | Ammonia | 35.9 |
| | Cyanide | 19.3 | Cyanide | 3.22 |
| | Phenols | 14.34 | Phenols | 1.79 |
| | Suspended Solids | 137. | Suspended Solids | 27.4 |
| 14H-TT | Ammonia | 306. | Ammonia | 24.5 |
| | Cyanide | 10.2 | Cyanide | 0.11 |
| | Phenols | 0.778 | Phenols | 0.19 |
| | Suspended Solids | 1680.0 | Suspended Solids | 337.0 |

TABLE 23 (continued)

| Outlet I.D. | 1977 BPT Allocations | BAT Loadings |
|---|---|---|
| Inland (cont.)<br>15H-TT | Ammonia 306.<br>Cyanide 10.22<br>Phenols 0.778<br>Suspended Solids 1680.0 | Ammonia 24.5<br>Cyanide 0.11<br>Phenols 0.19<br>Suspended Solids 337.0 |
| 16H-3 | Suspended Solids 14800. | Suspended Solids 2950.0 |
| 16F-1 | Suspended Solids 15900.0 | Suspended Solids 7950.0 |
| IE-2 | Not Treated-Minimal Loads | Not Treated-Minimal Loads |
| 10E-1 | No Treatment Required | No Treatment Required |
| 16H-1 | No Treatment Required | No Treatment Required |
| 16H-2 | No Treatment Required | No Treatment Required |
| Youngstown<br>YS-12(+13,22) | Ammonia 409.<br>Cyanide 20.4<br>Phenols 1.04<br>Suspended Solids 77.4 | Ammonia 32.7<br>Cyanide 0.204<br>Phenols 0.259<br>Suspended Solids 15.5 |
| YS-15 | Ammonia 969.0<br>Cyanide 38.6<br>Phenols 8.23<br>Suspended Solids 3600. | Ammonia 77.5<br>Cyanide 6.45<br>Phenols 1.03<br>Suspended Solids 720. |
| YS-18A | Ammonia 2020.0<br>Cyanide 91.0<br>Phenols 11.2<br>Suspended Solids 9640. | Ammonia 162.<br>Cyanide 15.2<br>Phenols 1.4<br>Suspended Solids 1930.2 |
| YS-20 | Suspended Solids 1500. | Suspended Solids 300. |
| YS-2 | No Treatment REquired | No Treatment Required |
| YS-4 | No Treatment Required | No Treatment Required |

TABLE 23 (continued)

| Outlet I.D. | 1977 BPT Allocations | BAT Loadings |
|---|---|---|
| Youngstown (cont.)<br>YS-8 | No Treatment Required | No Treatment Required |
| YS-11 | No Treatment Required | No Treatment Required |
| YS-14 | No Treatment Required | No Treatment Required |
| ARCO | Ammonia 96.0<br>Suspended Solids 1200.0<br>Phosphorus 4.0 | Ammonia 96.0<br>Suspended Solids 240.4<br>Phosphorus 4.0 |
| DuPont | Ammonia 150.0<br>Suspended Solids 2340.<br>Phosphorus 4.49 | Ammonia 150.0<br>Suspended Solids 468.<br>Phosphorus 4.49 |
| Gary STP | Ammonia 801.0<br>BOD 5760.0<br>Phenols 1.84<br>Cyanide 22.0 | Limits Not Defined |
| Hammond STP | Ammonia 619.0<br>BOD 2520.0<br>Phenols 1.47<br>Cyanide 17.0 | Limits Not Defined |
| East Chicago | Ammonia 1140.<br>BOD 2930.<br>Phenols 33.0<br>Cyanide 11.8 | Limits Not Defined |

Source: Combinatorics, Inc., (A Subsidiary of MATHEMATICA, INC.), Load Allocation Study of the Grand Calumet River and Indiana Harbor Ship Canal, Lafayette, Indiana, January, 1974.

## TABLE 24

## CUMULATIVE LOADS TO LAKE MICHIGAN
(3 Years)

| SUBSTANCE | LOAD |
|---|---|
| $BOD_5$ | 23,800,000 lbs. |
| $NH_3$ | 23,100,000 lbs. |
| Phenols | 910,000 lbs. |
| Cyanides | 4,790,000 lbs. |
| Phosphorus | 469,000 lbs. |
| Sulfates | 41,600,000 lbs. |
| Fluorides | 138,000 lbs. |
| Chlorides | 2,740,000 lbs. |

Source: MATHEMATICA, Inc.

## TABLE 25

## SUMMARY OF SENSITIVITY STUDIES

| Parameter & Value | Total Cost (Millions $) 1977 Compliance | Total Cost (Millions $) 1980 Compliance | Savings as a Percentage of 1977 Cost |
|---|---|---|---|
| Nominal Case | 475.5 | 474.0 | 0.3% |
| Discount Rate, 7% | 492.6 | 508.2 | -3.2% |
| Discount Rate, 10% | 439.7 | 415.0 | 5.6% |
| Discount Rate, 12% | 408.3 | 365.0 | 10.6% |
| Short Term Inflation Rate, 4% | 393.7 | 350.4 | 11.0% |
| Short Term Inflation Rate, 12% | 570.3 | 634.0 | -11.1% |
| Long Term Inflation Rate, 8% | 645.2 | 643.8 | 0.2% |
| Financing Interest Rate, 5% | 462.3 | 460.9 | 0.3% |
| Financing Interest Rate, 10% | 496.3 | 494.6 | 0.3% |
| Financing Interest Rate, 12% | 511.0 | 509.1 | 0.4% |

TABLE 25 (continued)

## SUMMARY OF SENSITIVITY STUDIES

| Parameter & Value | Total Cost (Millions $) 1977 Compliance | Total Cost (Millions $) 1980 Compliance | Savings as a Percentage of 1977 Cost |
|---|---|---|---|
| Municipal Investment %, 10% | 476.2 | 474.7 | 0.3% |
| Municipal Investment %, 15% | 475.0 | 474.4 | 0.3% |
| Total Investment Cost, -20% | 437.8 | 436.6 | 0.3% |
| Total Investment Cost,-10% | 456.6 | 455.3 | 0.3% |
| Total Investment Cost, +10% | 494.3 | 492.6 | 0.3% |
| Total Investment Cost, +20% | 513.1 | 511.3 | 0.3% |
| Investment Phasing 10%-20%-70% | 474.7 | 472.2 | 0.5% |
| Investment Phasing 10%-50%-40% | 476.4 | 474.8 | 0.3% |
| % Change in Ratio of Annual Investment to O&M Costs, -10% | 483.9 | 478.9 | 1.0% |
| % Change in Ratio of Annual Investment to O&M Costs, +10% | 464.4 | 464.2 | 3.2% |

## Discount Rate

Figure 26 shows the effect of the discount rate on estimated cost savings. Discount rates of 7%, 10% and 12% were tested in addition to the nominal 8% rate.

A negative savings means that 1977 compliance is less expensive than 1980 compliance.

For the nominal case (8%) the saving is only $1.5 million, or less than 1% of the total 1977 treatment cost. However, for the 7% discount rate the savings are negative indicating the rapid compliance is less expensive. An increase to 10% results in an increase in savings over the nominal case and at a 12% discount rate savings amount to $43 million or 10.6% of the original 1977 cost. It is unlikely that the discount rate will decrease in the near future.

## Short Term Inflation Rate

The short term inflation rate used up to the compliance date and applied primarily to construction costs, is nominally 8%, but is varied from 4% to 12%. The results are shown in Figure 27. Absolute savings are very sensitive to changes in short term inflation rates varying from a $43 million to -$63 million for inflation rates of 4% and 12% respectively. Savings relative to the total cost for 1977 are +11% for a 4% rate and drop as the inflation rate increases.

Thus, as the inflation rate increases, savings decrease, and in fact, above 8% it is more costly to delay compliance for three years than to meet 1977 targets.

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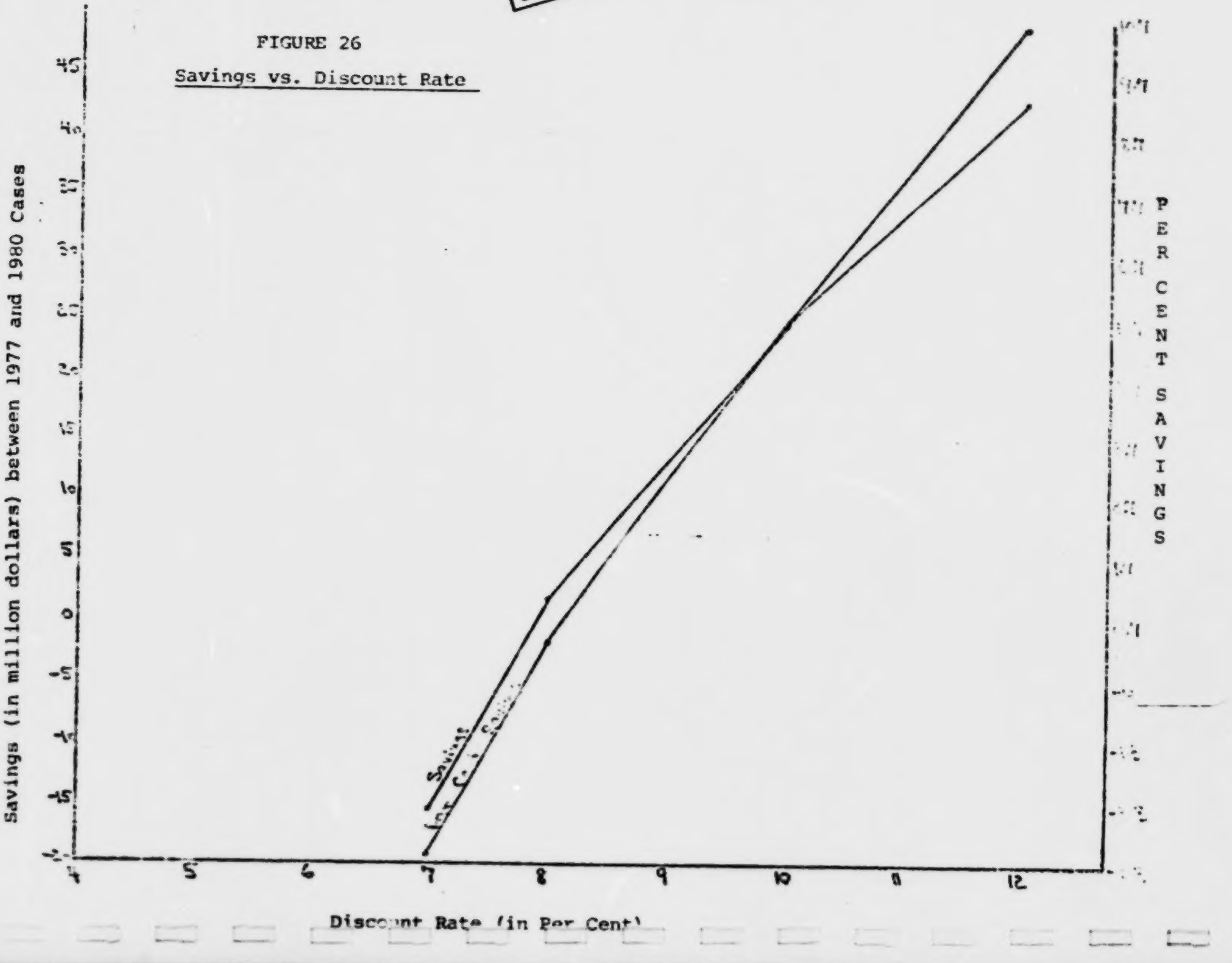
FIGURE 26

Savings vs. Discount Rate



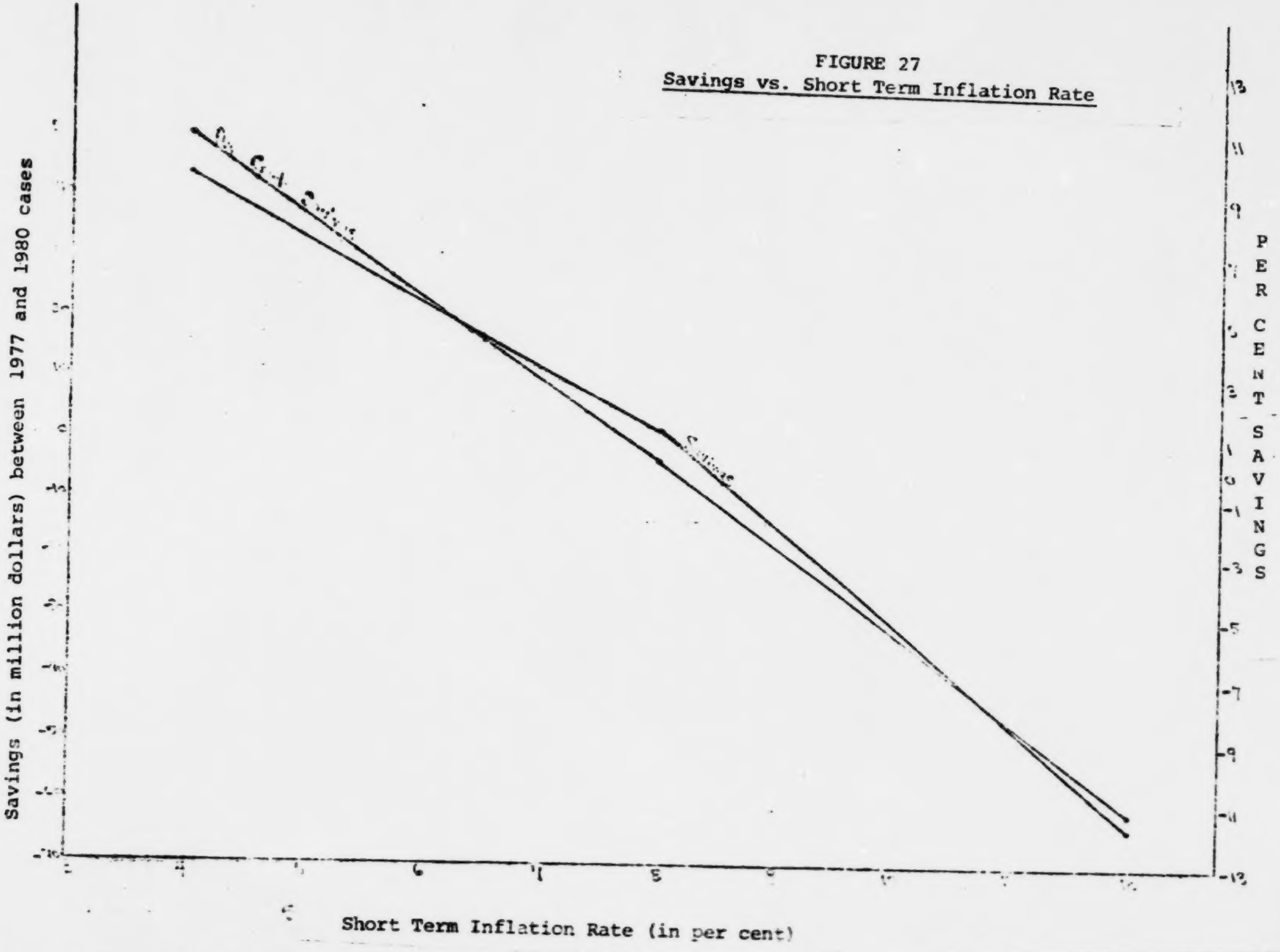


FIGURE 27
Savings vs. Short Term Inflation Rate

### Long Term Inflation Rate

The nominal long term inflation rate was 4% and was used to extrapolate the operations and maintenance costs over a 24 year plant life.

Only one other long term inflation rate (8%) is evaluated. The magnitude of the savings in delaying compliance is small, less than $1.4 million in absolute savings or approximately .2% of the 1977 base cost. Total cost savings are given as a function of long term inflation rates. (Figure 28)

### Financing Interest Rate

Financing interest rates of 5%, 10%, 12% are evaluated in addition to the nominal rate of 7%. The result of these runs are shown in Figure 29. Savings are insensitive to rather wide changes in the financing interest rate. Total costs as a function of financial interest rate is shown in Table 25.

### Municipal Investment Percentage

The municipal investment percentage is the fraction of the total investment which must be financed by the local municipality. The remaining costs are paid through a Federal grant.

The nominal municipal investment percentage is 25%. Two other municipal investment percentages are investigated, 15% and 10%. Results of these studies are given in Figure 30. The savings are insensitive to variation of the municipal investment percentage. Total costs versus municipal investment percentage is shown in Table 25.

FIGURE 28

Savings vs. Long Term Inflation Rate

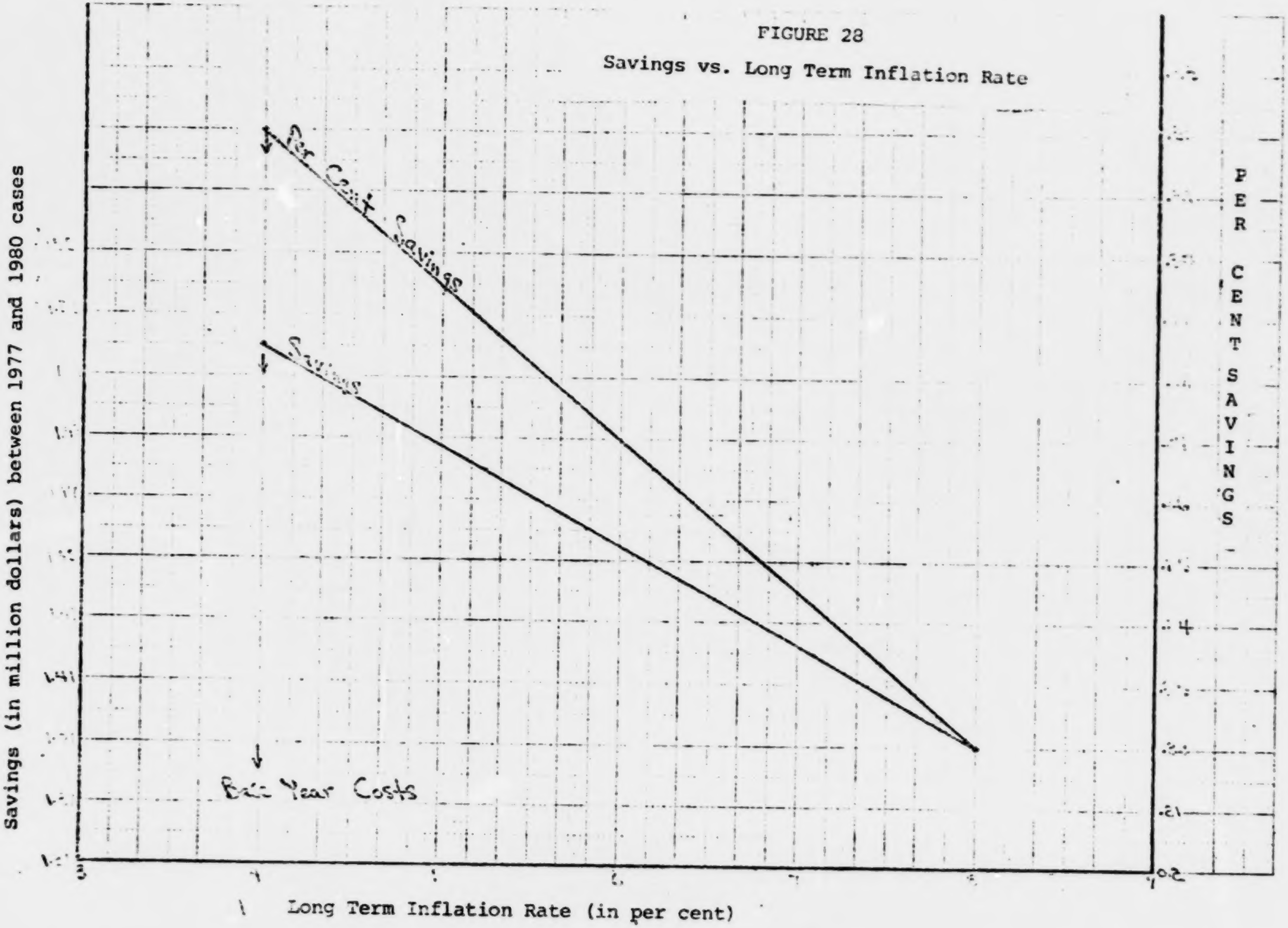
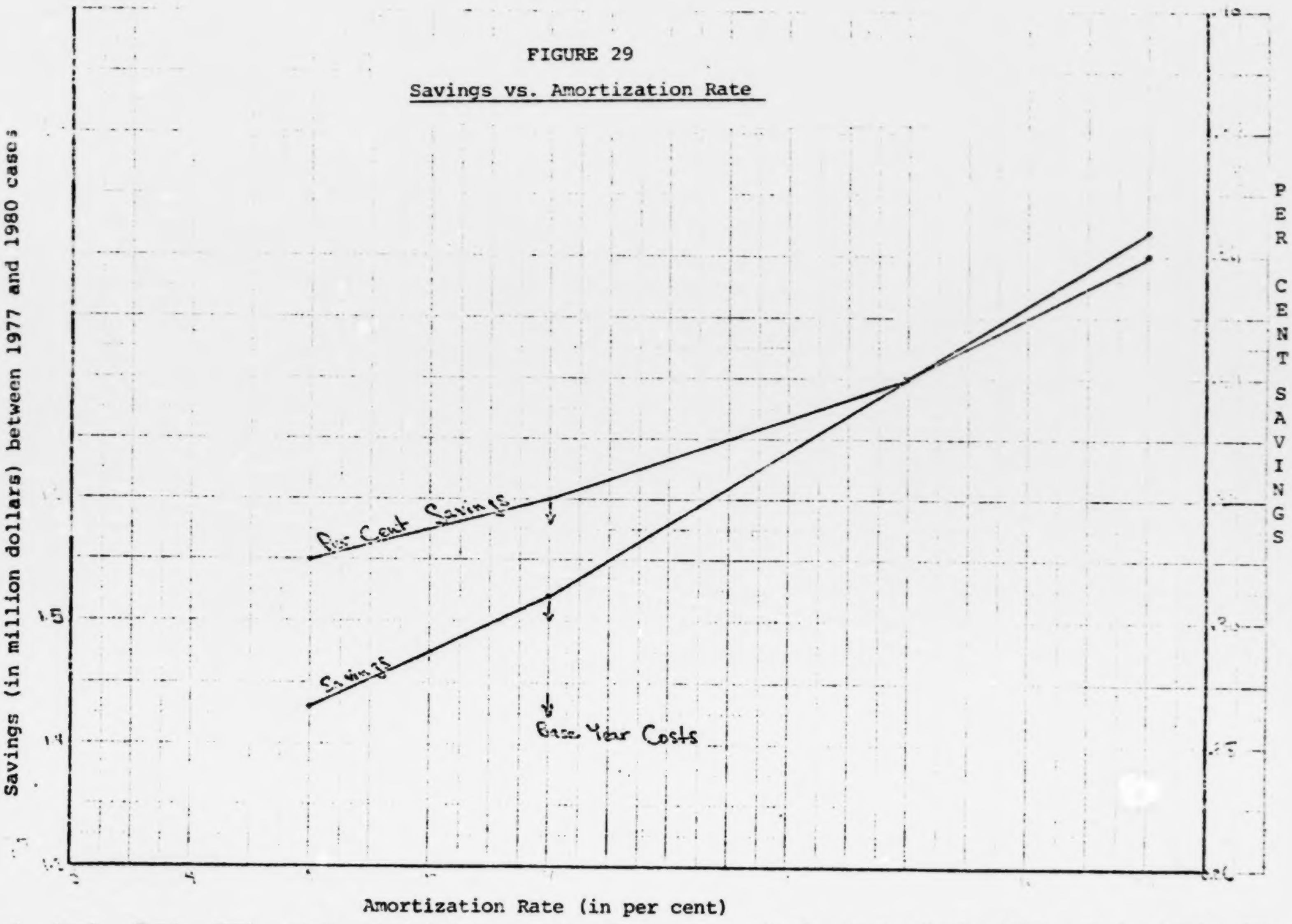


FIGURE 29

Savings vs. Amortization Rate



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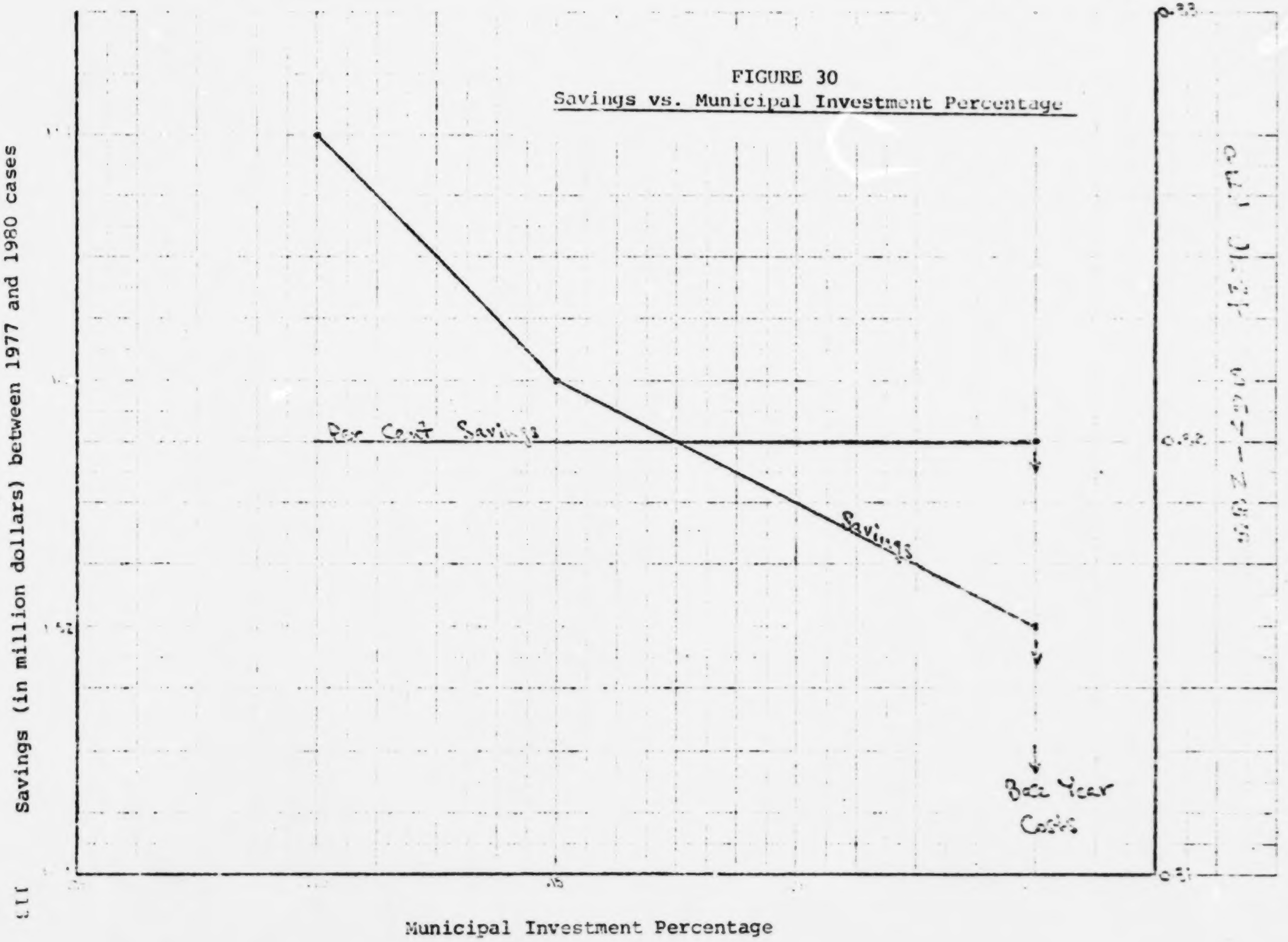


FIGURE 30
Savings vs. Municipal Investment Percentage

### Total Investment

Total investment costs include all municipal and industrial costs needed to meet water quality standards. The total investment costs are varied by ±10 and ±20.

Results of these studies are shown in Figure 31. Changes in the savings are negligible, not exceeding 0.4%.

### Ratio of Annual Investment to O&M Costs

The ratio of the annual investment to the annual O&M cost was varied for both 1977 and 1980 compliance. The nominal case was varied by ±10%. Figure 32 presents the results.

As before the savings are insignificant amounts approximately 1% of the total costs.

### Phasing Industrial Investment

The nominal case consisted of yearly investments during a three year construction period of 10%, 40% and 50% of the total capital costs respectively. This is referred to as a 10%-40%-50% three phase industrial investment.

Two other cases are studied, a 10%-20%-70% case, and a 10%-50%-40% case, with results shown in Figure 33. The variation of the investment percentages does not result in any significant changes in the savings.

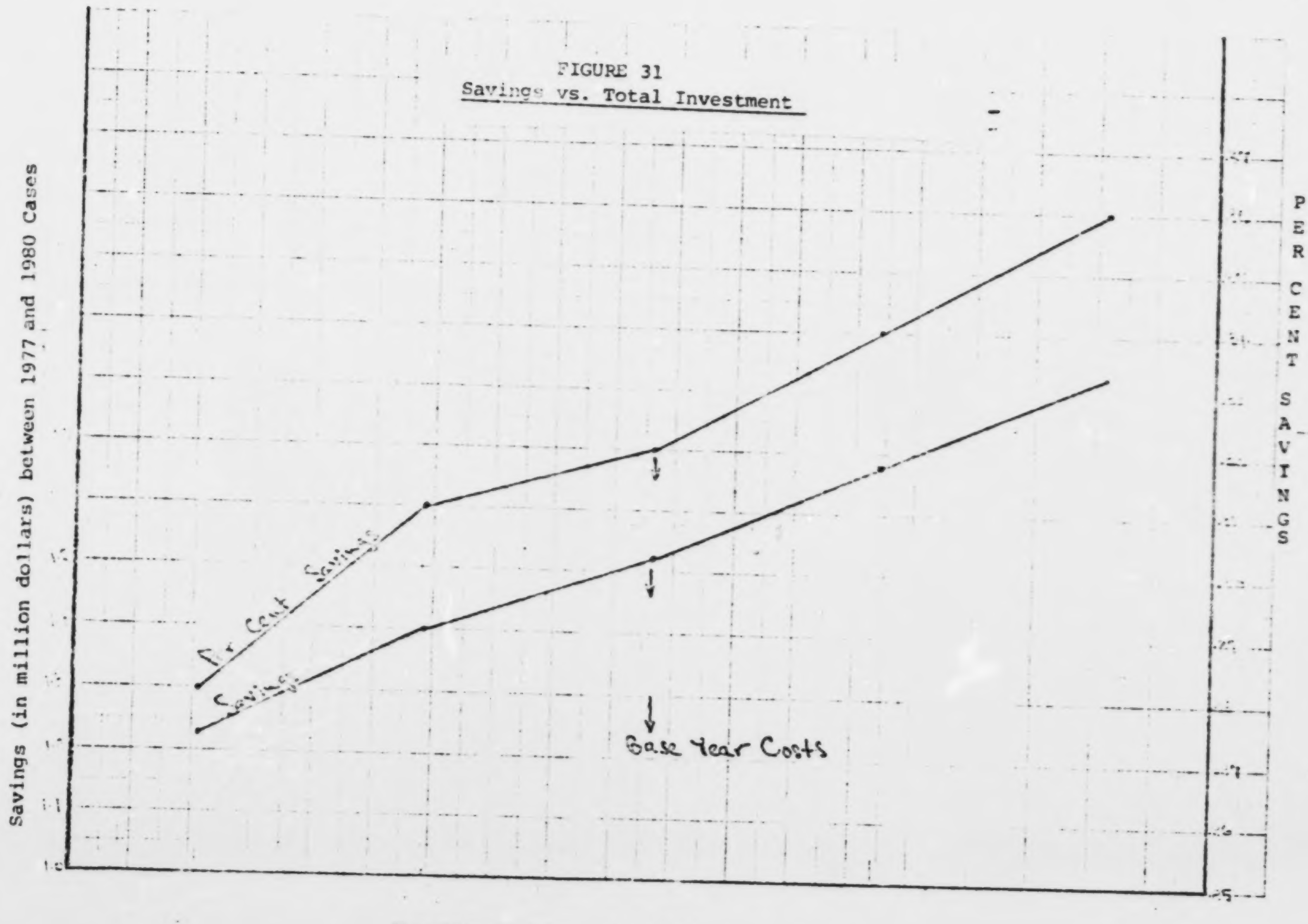


FIGURE 31

Savings vs. Total Investment

## FIGURE 32

Savings vs. Annual Investment/O/M Ratio

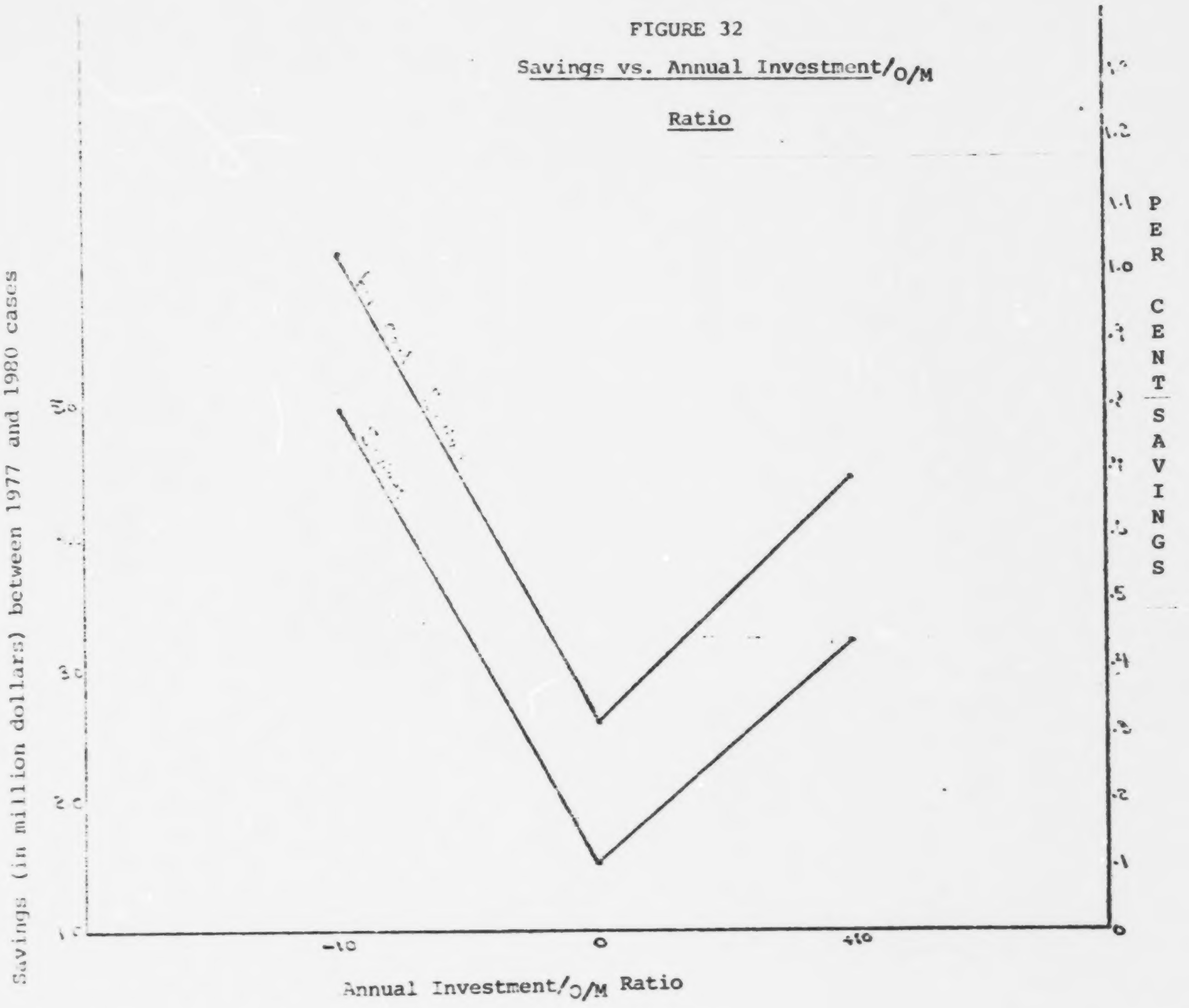
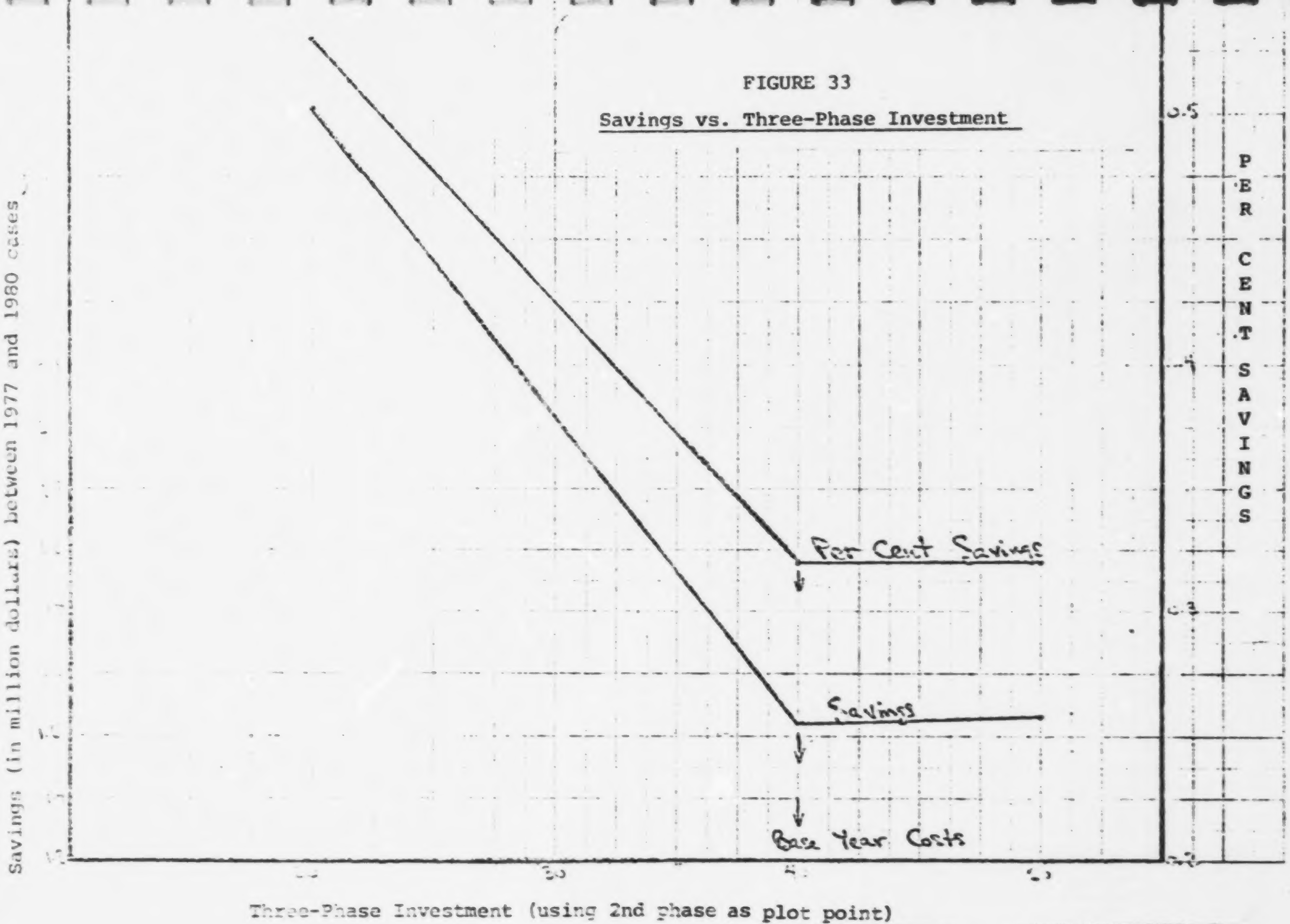


FIGURE 33

Savings vs. Three-Phase Investment



## BAT in 1983

The FWPCAA of 1972 requires that private discharges be upgraded to Best Available Treatment (BAT) by 1983 and public discharges to BPT in 1983. This requirement could conceivably affect the basic conclusion as to whether it is worthwhile to delay compliance from 1977 to 1980.

However, there are very serious problems in estimating the cost of compliance with 1983 standards. Some of these problems are listed below.

- BAT effluent guidelines for public treatment plants have not been defined.
- Treatment costs for some of the steel finishing processes including plating, galvanizing, coating and pickling are not available.
- Additional industrial discharges in miscellaneous categories would require special treatment trains designed specifically for them. In addition, for some types of outlets the ultimate source of the loads is not known.
- For power plant discharges for the steel industry, additional information is required in order to determine the type and degree of treatment required.
- Each of the EPA development document steel making processes involves a significant degree of recycling in its treatment train. Applying this degree of recycling to the Calumet Basin steel processes would make it practically impossible to meet the new water quality standards since the Grand Calumet is almost wholly constituted by wastewaters from industry and municipal plants. The catastrophic effects of recycling on water quality for a few discharges in the Calumet is amply described in the Reference . The state of

> Indiana has not decided on the approach to be taken to achieve water quality standards under significant recycling by the steel industry.

Therefore, it is possible to develop an incomplete estimate of the 1983 costs. For example, for the three major steel plants approximately 30% of the total treatable flow were not estimated for the various reasons cited above or because costs could not be developed within the constraints of the study.

However, with these limitations, 1983 BAT costs are estimated for the industrial discharges in the Calumet Basin and the methodology used to estimate these costs is very similar to that which was used for BPT estimates. It was asssumed that for BAT, the EPA level of treatment and the Calumet discharge treatment are identical.

Since phenols are already at BAT levels for the 1977 and 1980 cases, these costs (carbon column rental costs in the Development Document) were subtracted for each discharge that had dephenolization.

It was also assumed that there were no process charges other than recycling, and that no discharge was treated which had constituent loadings less than 5% of the total constituent loadings at BPT levels of treatment.

The results of this costing procedure are presented in Table 26. discharge by discharge, along with the BPT and BAT loads on the outlets for which treatment costs are calculated. Finally, the total costs and the total life cycle in 1974 dollars are given below.

## TABLE 26
## DISCHARGE BAT TREATMENT COSTS
## (1974 Dollars)

| Discharger I.D. | Investment | Operation & Maintenance |
|---|---|---|
| U.S. Steel | | |
| GW-1 | 1,489,000 | 451,000 |
| GW-2 | 1,182,000 | 358,000 |
| GW-3 | 432,000 | 131,000 |
| GW-5 (+2A,3A) | 1,828,000 | 212,000 |
| GW-6 | 601,000 | 54,000 |
| GW-7 | -- | -- |
| GW-7A | 2,063,000 | 197,000 |
| ST-17 | -- | -- |
| GW-9 | -- | -- |
| GW-10A | 4,320,000 | 532,000 |
| GW-11A | 8,557,000 | 1,054,000 |
| GW-4 | -- | -- |
| GW-13 | -- | -- |
| GW-14 | 62,000 | 8,000 |
| Inland | | |
| 4E-1 | 956,000 | 111,000 |
| 5E-2(+5E-1,5E-3) | 80,000 | 10,000 |
| 7E-1 (+6E-1) | 222,000 | 26,000 |
| 136-1 | 240,000 | 28,000 |
| 13H-1 | 520,000 | 61,000 |
| 14H-TT | 1,408,000 | 358,000 |
| 15H-TT | 1,408,000 | 358,000 |
| 16H-3 | 273,000 | 34,000 |
| 16F-1 | 1,382,000 | 117,000 |
| IE-2 | -- | -- |
| 10E-1 | -- | -- |
| 16H-1 | -- | -- |
| 16H-2 | -- | -- |

## TABLE 26 (continued)
## DISCHARGE BAT TREATMENT COSTS
## (1974 dollars)

| Discharger I.D. | Investment | Operation & Maintenance |
|---|---|---|
| Youngstown | | |
| YS-12 (+13,22) | 977,000 | 296,000 |
| YS-15 | 1,319,000 | 162,000 |
| YS-18A | 9,415,000 | 1,161,000 |
| YS-20 | 147,000 | 19,000 |
| YS-2 | -- | -- |
| YS-4 | -- | -- |
| YS-8 | -- | -- |
| YS-11 | -- | -- |
| YS-13 | -- | -- |
| YS-14 | -- | -- |
| ARCO | 125,000 | 15,000 |
| DuPont | 108,000 | 14,000 |
| Gary STP | -- | -- |
| Hammond STP | -- | -- |
| East Chicago STP | -- | -- |

Source: MATHEMATICA, Inc.

Industrial BAT

Total Investment Cost = $39.2 million
Total O&M = $87.1 million
Total Cost = $126.3 million

The significance of this total cost is not very high, when viewed against the limitations and uncertainties involved in this calculation. Consequently, this estimate was given little weight in considering its effect on the conclusion as to the delay in the 1977 compliance date.

Flow Diversion Alternative

One major alternative mentioned for protecting the water quality of Lake Michigan is the diversion of the Grand Calumet River away from the lake. This could be done by constructing a dam at the junction of the river and the canal. This act would have significant water quality benefits not only to Lake Michigan by diverting great sources of chlorides and sulfates from the Lake, but would also reduce the concentration of constituents in the west branch of the river by the additional flow from the east (Ref. 10)

Since this appears to be one of the most probable methods of attack on the water quality problem particularly after 1980 and under BAT requirements, the approximate cost for the dam is $2,987,000 (Reference 8). Net load reductions to Lake Michigan are based on the loads specified by the state of Indiana and are listed below.

| | |
|---|---|
| BOD5 | 11,500 lbs/day |
| Ammonia | 3,933 lbs/day |
| Phenols | 30.2 lbs/day |
| Cyanide | 158 lbs/day |
| Phosphorus | 150 lbs/day |
| Sulfates | 193,000 lbs/day |
| Fluorides | 3,340 lbs/day |
| Chlorides | 154,000 lbs/day |

### Industrial Technology Changes

An initial assumption was that water quality standards would be met through the application of end-of-pipe treatment as opposed to the modification of the basic industrial processes. It was felt that major process changes would not be possible within the constraint of 1977 compliance. However, it was also felt that process changes might be feasible within a 1980 compliance schedule, and detailed analysis of the steel industry was performed in order to determine when significant steelmaking process changes could affect water quality.

It was felt that no significant changes in water quality could be affected within ten years, and that potential steelmaking process changes do not alter the conclusions derived from the study based on end-of-pipe treatment. Details of the analysis of steelmaking processes are found in Appendix D.

## H. CONCLUSIONS - CALUMET BASIN

By delaying compliance with 1977 water quality standards to 1980, the savings to the municipalities and industries would be approximately $1.5 million or .32%, a very insignificant amount.

Almost two-thirds of the total cost of BPT clean-up for the three major steel companies is attributable to meeting BAT phenol effluent levels.

The environmental costs of the three year delay would be three more years of existing heavy loads to Lake Michigan. Since the savings are so small, a three year delay does not appear to be worthwhile.

The sensitivity analyses indicate that only variations in the short term inflation rate and the discount rate have any significant effect on savings. If the short term inflation is 12%, a three year delay is more expensive than 1977 compliance by 11.2%. However, higher inflation rates result in higher discount rates and the initial conclusions are still valid. Consequently, even with wide variations in the discount rate and short term inflation rate, the basic conclusion remains the same. A three year delay in compliance with 1977 standards is not warranted economically or environmentally.

## SECTION VI

## INVESTMENT PLANNING CRITERIA

The allocation of the costs of accomplishing the water quality goals specified in the 1972 FWPCAA must be weighed against several different criteria. Each criterion focuses on a different aspect of cost allocation. Four criterion considered and utilized in the course of this study are discussed below.

### A. EFFICIENCY

As specified in early discussions with EPA staff, efficiency is to be discussed in terms of cost effectiveness. While this term provides a broad conceptual background for considering economic efficiency, it is necessary to translate this framework into specific measures for use in this study.

The first measure to be explicitly stated was the definition of cost. There are several different costs which are developed in the conduct of this study including investment costs, operating and maintenance costs and interest costs. Any systematic analysis must consider each of these components and bring them to a common set of measures. The use of life cycle costs provides such a mechanism in that all costs incurred during the lifetime of a piece of equipment or waste treatment plant are totaled and compared. However, as required by Principals and Standards for Planning Water & Related Land Resources and by Circular A-94 the value of all future costs must be properly discounted to reflect the current value of such costs. For a discussion of the rationale requiring discounting of future benefits see Reference 21.

In determining the life cycle total cost, a discount rate is used to compute the present value of future costs. The rate is set in two basic documents (References 19 & 58). The rate set by OMB at 10% applies to all federal projects but specifically excepts water resource projects. The Principals as put forth by the Water Resources Council (Sept. 10, 1973) set the discount rate at the average cost of Federal borrowing as determined by the Secretary of Treasury. The rate for FY 1974 was initialyzed at 6 7/8 percent and is constrained to change by no more than 0.5 percent per year. It is likely then that the rate for FY 1975 will be 7 3/8 percent. Analysis was conducted to test the sensitivity of the study conclusion for discount rates ranging from 4% to 12%.

A second measure is required for the application of a cost effectiveness framework and that is some measure of "economic effectiveness" or "benefits".

In this study, cost savings are treated as benefits. That is, the decrease in life cycle cost of waste treatment achieved by delaying compliance is considered a "benefit". In some instances this decrease may not occur and total costs may increase resulting in "negative benefits".

In summary, life cycle costs were used with benefits defined as cost savings over the project lifetime. All future costs were discounted to determine the present value of all lifetime costs.

## B. EFFECTIVENESS

Effectiveness is an additional criterion intended to provide a measure of the degree to which water quality is enhanced. Various measures have been suggested including (1) miles of stream cleaned up, (2) the number of sources brought within standards, and (3) the mass of pollutant removed. In this study the first two measures are not appropriate because the study examines the effect of changing the time period allowed for compliance with specified stream standards. Therefore, all sources are brought to a level of treatment complying with the requirements of the 1972 FWPCAA. In addition, because the case studies involve water quality limited segments, the entire segment is brought into compliance under all scenarios.

Therefore, the only measure remaining is the mass of pollutant removed. This measure takes on two different aspects as a function of the particular case study.

In the simplest case, abatement is delayed by three years, and the pollution loadings, for both 1977 and 1980 compliance are identical. However, 1980 compliance would allow three years of additional discharge to the river and the total mass of this discharge over this period can be utilized as a measure of effectiveness.

In the more complex scenario, a three year period is required to implement a different,more cost efficient treatment program. In this case, total mass discharged can vary as a function of several variables. First, the regional approach allows the effluent to be discharged at a point in the stream where the water body's natural assimilative capacities are highest. Thus several small flows, requiring AWT, would be combined and might be treated to only the secondary level and discharged to the stream. In this case, although the treatment program might be more effective, the total mass of pollutants discharged might be greater with the regional solution. However, water quality standards would be satisfied in either case.

A second factor is that during the time period required to achieve this alternative program, pollutant discharges might continue unabated, resulting in an overall increase in loads. It is possible to quantify these load differences.

The above discussion has focused on the more easily quantified measures of effectiveness. However, water resource planners must consider all measures of effectiveness including recreational, social and aesthetic even though they are considerably more difficult to deal with. There is considerable research currently ongoing to identify, and describe, and where possible to quantify, some of these "intangibles". Furthermore, in this study we are concerned with the problem of delaying these benefits for up to three years and estimating the value of such a delay. This task is clearly beyond the scope of this study.

Therefore, in summary, the measure of effectiveness utilized in this study is the mass of pollutants removed, although under the basic constraint that any solution must meet water quality standards, this measure is of diminished importance.

## C. EQUITY

Equity, often used synonomously with fairness, is an important criterion to be considered in the evaluation of water resource alternatives. Unfortunately, both terms do not lend themselves to ease of use or transformation into easily quantified measures. Fortunately, equity is not a primary issue in the evaluation of these studies for the following reasons.

Equity is of primary concern in the allocation of loads among all dischargers to a stream. The least cost load allocation may meet the standard of minimizing social cost, however, it may require one discharger to reduce his load by 99%, and require no treatment in excess of BPT for a second discharger to the same stream. This second discharger may have located either prior to or after the initial discharger, but because of the characteristics of the stream may have picked a "better" spot. In addition, if discharger "two" were not around, the first discharger might only need to implement BPT. Depending on individual concepts of equity and fairness this might be considered as an inequitable distribution of loads and the required levels of treatment might be adjusted so that both dischargers share the cost of additional treatment. However, others might regard this adjustment as inequitable! In the case studies conducted, load allocations as approved by the respective states* were utilized. We have assumed that these allocations are consistent with the prevalent attitude toward equity as evidenced by the state. A second factor to be considered is that the study investigates the temporal distribution of costs over a constant set of investors. We are not examining the distribution of costs among investors.

One interpretation of equity requires that dischargers be responsible for their effluents and that these effluents not be passed downstream. This consideration of equity requires that treatment costs not be externalized by directing discharges from the basin under consideration. For example, all Meramec discharges could be collected and discharged directly to the Mississippi. This would reduce treatment requirements for the Meramec Basin, by externalizing the requirement for advanced treatment. While this action might actually be implemented for specific basins, this option is not generally available. Therefore, an additional constraint, that all effluents be treated and discharged within the study basin, was imposed. This constraint acted to reduce the total cost savings available from regionalization of the Meramec Basin as was discussed in the case study.

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*Missouri is finalizing the Meramec allocations.

The concept of equity does come into consideration in one additional respect. Through the 1972 Amendment, Congress has directed that a specified set of actions be taken and that costs be incurred according to some concept of fairness. The benefits of these actions accrue to many different groups, but Congress required that these benefits be available in 1977, with additional benefits available in 1983 and 1985. A delay in compliance challenges the equity of that initial Congressional distribution of costs among dischargers and those who would benefit from increased abatement. This latter question is within the pervue of Congress, however, and this study only attempts to identify options and their consequences.

## D. FEASIBILITY

The criterion of feasibility includes both physical or engineering feasibility and political, legal and administrative feasibility. In both case studies, feasibility was a primary consideration. In the study of the Meramec regionalization required consideration of both physical and institutional constraints. In addition to the time required to construct the larger and more complex regional system, it was also necessary to estimate the time required to institute the administrative and political mechanisms required for regional systems. Full regionalization of the Meramec was estimated to require an additional three years.

In the case study of the Calumet, alternative treatment programs were limited to those engineering possibilities deemed feasible. Both major recycling and a major diversion were considered to be physically feasible and their consequences investigated.

In considering the formulation of specific recommendations for adoption by EPA, the requirement that they be readily implementable was strongly considered. Any recommendation which would require an unwieldy administrative or procedural process was heavily discounted, since a primary consideration was that any benefits obtainable through a shift in compliance date be made available with minimal perturbations of the existing institutional and administrative structure.

# SECTION VII

# NATIONAL IMPLICATIONS

## A. GENERALIZATION OF CASE STUDY CONCLUSIONS

This project included two case studies of water quality limited segments to determine how a shift in compliance date is related to water quality and total abatement cost. The following conclusions can be drawn from these two studies:

(1) For highly heterogeneous effluents as would most likely be found from industrial dischargers, there are no significant cost savings resulting from a three year delay in compliance with 1977 standards;

(2) For highly homogenous effluents, typical of municipal sanitary dischargers, there is a potential for significant cost reductions under certain conditions.

Simply stated, the conditions necessary for cost savings with minimal adverse environmental effect are that there be a feasible regionalization alternative where requirements for AWT can be reduced by more fully utilizing the stream's natural assimilative capabilities

The decrease in costs resulting from economies of scale is approximately equal to the increase in cost for the interceptors required for regionalization. Appreciable cost savings result only from the decreased requirement for AWT. Therefore, cost savings are only possible in water quality limited stream segments, where treatment in excess of BPT for private dischargers and secondary level municipal discharges is required. Based on the case studies, there are no appreciable cost savings resulting solely from a shift in the compliance date without a corresponding change in the required treatment levels.

In summary then, the case studies indicate that delaying compliance with 1977 standards is only advantageous in water quality limited segments where disaggregated municipal sanitary discharges require considerable AWT. Combining effluents and discharging at a more suitable river stretch can appreciably decrease total cost. The next step is to assess the implications of this conclusion on a national scale.

### B. NATIONAL IMPACT

In order to determine the national impact of allowing delays in compliance where appreciable cost savings can be shown, it is necessary to derive some estimate of the total numbers of water quality limited stream segments where regional aggregation of effluents is feasible. The EPA Office of Water Planning and Standards was able to provide listings of water quality information for various stream segments on a state by state basis. A sample of the information provided is shown in Figure 34.

To augment this data, a telephone survey of EPA regional offices was conducted. In addition to tabulating the number of segments which were designated as water quality limited, the number of urban water quality segments and the number of segments where municipal flows could be aggregated was also estimated. This effort resulted in uncertain results because of the inadequacy of the data as reported by the states to the EPA regions. A visit to Region III and a review of data on file there confirmed that state reporting formats were inconsistent and sometimes very inconclusive. For example, Virginia provides a classification for each segment of major streams and using a map, an accurate estimate of the desired information can be made. Pennsylvania, on the other hand, has divided the state into 28 areas with each area being designated as effluent limited, water quality limited or a mine acid problem. Any estimate of the potential for cost savings in Pennsylvania would be very uncertain. A review of the data reported by

FIGURE 31

## STATE WATER QUALITY INVENTORY

| RW | ST | BA | SG | C | DESCRIPTION OF SEGMENT | W Q S STATUS |
|---|---|---|---|---|---|---|
| 05 | IN | 00 | 00 |  | INDIANA |  |
| 05 | IN | 01 | 00 |  | LAKE MICHIGAN RIVER BASIN |  |
| 05 | IN | 01 | 01 | W | CALUMET RIVER | 1983 |
| 05 | IN | 01 | 02 | W | DEEP RIVER | 1983 |
| 05 | IN | 01 | 03 | W | LITTLE CALUMET RIVER (EAST) | 1983 |
| 05 | IN | 01 | 04 | W | TRAIL CREEK | 1983 |
| 05 | IN | 02 | 00 |  | ST. JOSEPH RIVER BASIN |  |
| 05 | IN | 02 | 01 | W | TURKEY - BAUGO CREEKS | 1983 |
| 05 | IN | 02 | 02 | W | UPPER ELKHART RIVER | 1983 |
| 05 | IN | 02 | 03 | W | UPPER PIGEON CREEK | 1983 |
| 05 | IN | 02 | 04 | E | ST. JOSEPH RIVER (MAIN STEM) | 1977 |
| 05 | IN | 02 | 05 | E | LOWER ELKHART RIVER | 1977 |
| 05 | IN | 02 | 06 | E | LITTLE ELKHART - LOWER PIGEON RIVERS | 1977 |
| 05 | IN | 03 | 00 |  | KANKAKEE RIVER BASIN |  |
| 05 | IN | 03 | 01 | W | KINGSBURY CREEK | 1983 |
| 05 | IN | 03 | 02 | W | UPPER KANKAKEE RIVER | 1983 |
| 05 | IN | 03 | 03 | W | UPPER YELLOW RIVER | 1983 |
| 05 | IN | 03 | 04 | W | CEDAR CREEK | 1983 |
| 05 | IN | 03 | 05 | E | LOWER KANKAKEE RIVER | 1977 |
| 05 | IN | 03 | 06 | E | IROQUOIS RIVER | 1977 |
| 05 | IN | 03 | 07 | E | LOWER YELLOW RIVER | 1977 |
| 05 | IN | 04 | 00 |  | MAUMEE RIVER BASIN |  |
| 05 | IN | 04 | 01 | W | CEDAR CREEK | 1983 |
| 05 | IN | 04 | 02 | W | MAUMEE RIVER (MAIN STEM) | 1983 |
| 05 | IN | 04 | 03 | E | ST. JOSEPH RIVER | 1977 |
| 05 | IN | 04 | 04 | E | ST. MARY'S RIVER | 1977 |
| 05 | IN | 05 | 00 |  | WABASH RIVER BASIN |  |
| 05 | IN | 05 | 01 | W | WILDCAT - S. FORK WILDCAT CREEK | 1983 |
| 05 | IN | 05 | 02 | W | MIDDLE MISSISSINEWA RIVER | 1983 |
| 05 | IN | 05 | 03 | W | WABASH RIVER AT HUNTINGTON | 1983 |
| 05 | IN | 05 | 04 | W | UPPER PATOKA RIVER | 1983 |
| 05 | IN | 05 | 05 | W | UPPER SALAMONIE RIVER | 1983 |
| 05 | IN | 05 | 06 | E | BIG PINE CREEK | 1977 |
| 05 | IN | 05 | 07 | E | BIG MONON CREEK | 1977 |
| 05 | IN | 05 | 08 | E | LOWER TIPPECANOE RIVER | 1977 |
| 05 | IN | 05 | 09 | E | MIDDLE TIPPECANOE RIVER | 1977 |
| 05 | IN | 05 | 10 | E | UPPER TIPPECANOE RIVER | 1977 |
| 05 | IN | 05 | 11 | E | LOWER EEL RIVER | 1977 |
| 05 | IN | 05 | 12 | E | PIPE CREEK | 1977 |
| 05 | IN | 05 | 13 | E | WABASH RIVER - HUNTINGTON TO LOGANSPORT | 1977 |
| 05 | IN | 05 | 14 | E | UPPER EEL RIVER | 1977 |
| 05 | IN | 05 | 15 | E | LITTLE WABASH RIVER | 1977 |
| 05 | IN | 05 | 16 | E | WABASH RIVER - ABOVE HUNTINGTON | 1977 |
| 05 | IN | 05 | 17 | E | LOWER SALAMONIE RIVER | 1977 |
| 05 | IN | 05 | 18 | E | UPPER MISSISSINEWA RIVER | 1977 |
| 05 | IN | 05 | 19 | E | WABASH RIVER - LOGANSPORT TO DELPHI | 1977 |
| 05 | IN | 05 | 20 | E | DEER CREEK | 1977 |
| 05 | IN | 05 | 21 | E | M. FORK WILDCAT CREEK | 1977 |
| 05 | IN | 05 | 22 | E | WABASH RIVER - DELPHI TO ATTICA | 1977 |
| 05 | IN | 05 | 23 | E | WABASH RIVER - ATTICA TO COVINGTON | 1977 |
| 05 | IN | 05 | 24 | E | WABASH RIVER - COVINGTON TO NEWPORT | 1977 |
| 05 | IN | 05 | 25 | E | COAL CREEK | 1977 |
| 05 | IN | 05 | 26 | E | LOWER SUGAR CREEK | 1977 |
| 05 | IN | 05 | 27 | E | UPPER SUGAR CREEK | 1977 |
| 05 | IN | 05 | 28 | E | WABASH RIVER - NEWPORT TO TERREHAUTE | 1977 |
| 05 | IN | 05 | 29 | E | RACCOON CREEK | 1977 |
| 05 | IN | 05 | 30 | E | WABASH RIVER - TERRE HAUTE TO KNOX COUNTY | 1977 |
| [illegible] | IN | [illegible] | [illegible] | E | [illegible] | 1977 |
| [illegible] | IN | 05 | 32 | E | [illegible] | 1977 |

other regions and telephone conversations with regional staff indicated that similar problems existed in other regions.

The information generated from these two sources, The EPA Office of Water Planning and Standards and EPA regional offices is shown in Table 27. It should be emphasized that there is considerable uncertainty in this data and any attempt to develop absolute policies from it must be somewhat tentative.

There are several items of interest readily observable from the data in Table 27. First a number of states are entirely classified as water quality or effluent limited. Second, a review of the source data confirms that segment definitions vary among states and that a segment can be any area from an entire state (Utah) to a stretch of a river. The data shown in the table must be used with extreme caution.

In the 1973 "Needs" survey as reported to Congress (Reference 43). EPA asked local authorities to report the costs for construction of municipal treatment and collection facilities which were eligible for Federal funding under the 1972 Act and subject to other guidelines as specified by EPA. The results are listed in Table 28, however, total costs are estimated to be over $60 billion.

It is not reasonable to assume that the entire $5.6 billion for category II, treatment "More Stringent" than secondary as required to meet water quality standards could be saved by delaying compliance. Based on the data in Table 27, 286 of 617 segments labeled as water quality limited are believed to have municipally caused problems. In addition, there are six states in which all

TABLE 27

STREAM CLASSIFICATIONS

| STATE | Segment Gazetteer |  |  |  | Survey of EPA Regions |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  | Total Number of Segments | Water Quality Limited | Effluent Limited | Unknown | Total Number of Segments | Water Quality Limited | Effluent Limited | Other | Municipal DO Violators |
| Conn. | 34 | 8 | 0 | 26 | - | 23 | - | - | 6 |
| Mass. | 335 | 222 | 91 | 22 | - | 45 | - | - | 12 |
| Maine | 12 | 12 | 0 | 0 | - | 16 | - | - | 2 |
| N.H. | 42 | 11 | 31 | 0 | - | 10 | - | - | 3 |
| R.I. | 10 | 5 | 3 | 2 | - | 4 | - | - | 2 |
| Vt. | - | - | - | - | - | - | - | - |  |
| N.J. | 25 | 20 | 5 | 0 | - | 20 | 8 | - | - |
| N.Y. | 110 | 50 | 58 | 2 | - | 74 | - | - | - |
| Del. | 20 | 6 | 14 | 0 | - | 5 | - | - | - |
| Md. | 46 | 45 | 1 | 0 | 139 | 60 | 79 | - | - |
| Pa. | 51 | 28 | 19 | 4 | 28 | 15 | 8 | 5 | - |
| Va. | 145 | 78 | 67 | 146 | 74 | 72 | - | - | - |
| W.V. | 41 | 30 | 11 | 0 | 41 | 29 | 12 | - | - |
| Al. | 27 | 12 | 14 | 1 | 368 | 268 | 100 | - | - |
| Fl. | 38 | 15 | 5 | 18 | 115 | 90 | 25 | - | - |
| Ga. | 46 | 46 | 0 | 0 | 235 | 200 | 35 | - | - |
| Ky. | 10 | 10 | 0 | 0 | 486 | 356 | 130 | - | - |
| Ms. | 92 | 92 | 0 | 0 | 606 | 439 | 167 | - | - |
| N.C. | 126 | 29 | 97 | 0 | 128 | 28 | 100 | - | - |
| S.C. | 17 | 17 | 0 | 0 | 75 | 52 | 23 | - | - |
| Tn. | 19 | 6 | 13 | 0 | 167 | 119 | 48 | - | - |
| Il. | 123 | 34 | 89 | 0 | 123 | 123 | 0 | - | - |
| In. | 97 | 40 | 57 | 0 | - | 40 | - | - | 40 |
| Mi. | 17 | 16 | 0 | 1 | - | 16 | - | - | 16 |
| Mn. | 44 | 34 | 10 | 0 | - | 34 | - | - | 34 |
| Oh. | 142 | 84 | 0 | 58 | - | 234 | - | - | 234 |
| Wi. | 50 | 16 | 34 | 0 | - | 17 | - | - | 17 |
| Ar. | 37 | 0 | 37 | 0 | 35 | 35 | - | - | - |
| La. | 109 | 21 | 88 | 0 | - | 21 | - | - | - |
| N.M. | 47 | 6 | 41 | 0 | - | 5 | - | - | - |

TABLE 27 (continued)

| STATE | Segment Gazetteer (1) |  |  |  | Survey of EPA Regions (2) |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  | Total Number of Segments | Water Quality Limited | Effluent Limited | Unknown | Total Number of Segments | Water Quality Limited | Effluent Limited | Other | Municipal DO Violators |
| Ok. | 41 | 40 | 0 | 1 | 43 | 43 | - | - | - |
| Tx. | 278 | 59 | 219 | 0 | - | 63 | - | - | - |
| Iw. | 41 | 34 | 7 | 0 | 39 | 4 | - | - | 4 |
| Ks. | 62 | 0 | 62 | 0 | - | - | - | - | - |
| Mo. | 85 | 15 | 70 | 0 | - | 15 | - | - | 4 |
| Nb. | 149 | 15 | 134 | 0 | - | 17 | - | - | 6 |
| Co. | 29 | 9 | 20 | 0 | - | 21 | - | - | 10 |
| Mt. | 32 | 16 | 16 | 0 | 16 | 16 | - | - | 1 |
| N.D. | 11 | 2 | 9 | 0 | - | 5 | - | - | 1 |
| S.D. | 68 | 56 | 12 | 0 | - | 62 | - | - | 3 |
| Ut. | 1 | 1 | 0 | 0 | - | 12 | - | - | Entire State |
| Wy. | 11 | 4 | 7 | 0 | - | - | - | - | - |
| Az. | 20 | 12 | 8 | 0 | - | 10 | - | - | 6 |
| Ca. | 169 | 32 | 137 | 0 | - | 31 | - | - | 12 |
| Hi. | 30 | 10 | 20 | 0 | - | - | - | - | - |
| Nv. | 35 | 14 | 21 | 0 | - | 16 | - | - | - |
| Ak. | 15 | 0 | 4 | 11 | - | - | all | - | Ocean Dumping |
| Id. | 30 | 24 | 6 | 0 | - | 125 | - | - | 91 |
| Or. | 85 | 85 | 0 | 0 | 82 | 82 | - | - | 8 |
| Wa. | 140 | 127 | 13 | 0 | - | 115 | - | - | 115 |

Source:

(1) U. S. Environmental Protection Agency, National Water Quality Inventory, 1974 Report to Congress, EPA-440/9-74-001, Volumes 1 and 11.

(2) MATHEMATICA, Inc.

## TABLE 28

## NATIONAL WASTEWATER COSTS

| | Cost Category | Cost (billion dollars) |
|---|---|---|
| I | Secondary Treatment Required by the Act | 16.6 |
| II | Treatment "More Stringent" than Secondary Required by Water Quality Standards | 5.6 |
| III | Rehabilitation of Sewers to Correct Infiltration and Inflow | 0.7 |
| IV | New Sewers | 24.4 |
| V | Correction of Overflows from Combined Sewers | 12.7 |

Source: U. S. Environmental Protection Agency, *Costs of Construction of Publicly-Owned Wastewater Treatment Works, 1973 "Needs" Survey*, An EPA Report to Congress, November, 1973.

water quality segments (345 segments) are thought to be municipal problems and one state, Utah, which is entirely water quality limited. Finally, there are 2,159 water quality limited segments in 21 states for which no municipal problems are estimated. This data was generated in a telephone survey of EPA regional offices and is subject to considerable uncertainty as stated earlier. However, if it is used, the following estimates are possible.

Of the total of 962 segments in states for which there is an estimate of municipally-caused water quality problems, 631 or 66% were thought to be amenable to regionalization. If all segments are included, then the percentage drops to 20%. Again, the state of Utah is excluded. Based on these percentages, it is possible that a maximum of $1.1 billion to $3.7 billion could be saved if all AWT were eliminated. However, even under the best conditions as found in the Meramec study, Figure 14, only 70% of the costs of AWT could be eliminated. Therefore, the above savings are further reduced to a maximum of between $770 million and $2,580 million.

Therefore, out of a total estimated municipal cost of $60 billion, selective extensions of the 1977 compliance date for publicly owned treatment works can result in savings of from $.77 billion to $2.58 billion.

Because of the basic uncertainties inherent in the data, it was felt that there was no advantage to be gained in using the survey data to estimate savings on a state-by-state basis. One recommendation is that this data be collected and state estimates prepared.

The next section provides guidelines as to how a program to realize these savings can be instituted.

## C. IMPLEMENTATION

While delaying the date of compliance with the 1977 water quality standards can result in significant cost savings, not every water quality segment will be able to realize these benefits. Therefore, an across the board extension for all dischargers is not necessarily the best mechanism for achieving these benefits, and would result in delays in the implementation of programs for which there are no cost savings.

Therefore, it is recommended that EPA institute a system whereby specific states are allowed extensions only upon presentation of evidence by the state which demonstrates:

(1) that the state has developed a plan for compliance with the 1977 standards by July 1, 1977;
(2) that there are treatment alternatives available which result in significant life cycle cost savings over the plan proposed for 1977 compliance;
(3) that the implementation of the less costly alternative cannot be completed by 1977 by providing an implementation schedule resulting in full compliance; and
(4) a statement of the adverse and beneficial environmental consequences of the delay.

Each of these conditions should be satisfied prior to the issuance of a variance.

In order to implement this recommendation, it is also suggested that EPA prepare a set of guidelines for use by state governments in determining whether or not a delay is warranted. These guidelines should include at a minimum:

(1) a description of the conditions under which delays will be allowed,

(2) a description of the process to be used by the states to estimate the benefits of a delay,

(3) a listing of the information required to support any application for a variance, and,

(4) the format for presenting such requests.

In addition, it is necessary that EPA develop criteria for approval (rejection) of requests, and the necessary mechanisms for reviewing and approving (rejecting) requests. These recommendations will allow extensions of the compliance period where justified and do not require the development of large administrative staffs to evaluate and respond to requests for extensions.

Studies required to determine whether or not an extension will result in cost savings are themselves expensive and there is no assurance that a net benefit will be the result. Therefore, it is necessary to develop a set of guidelines which can be easily used by state personnel to determine whether a more detailed study is warranted.

These guidelines would be applied to specific basins and would allow states to estimate costs prior to incurring the expense of a major water planning project requiring water quality models and rigorous cost estimates.

In order to encourage states to request appropriate extensions, EPA should develop a set of guidelines and estimating techniques which states can utilize to determine if a request for a variance should be investigated in depth.

# SECTION VIII
## RECOMMENDATIONS

As pointed out in the previous section, significant cost savings are available in water quality limited segments, if compliance with water quality goals in 1977 can be delayed. It was estimated that maximum savings will be between $770 million and $2,580 million. However, because of the lack of confidence in the estimate of the number of segments which could realize these savings the estimate is highly uncertain. The problems encountered in obtaining an estimate of water quality segments where regionalization is feasible were discussed previously. It is recommended that a state by state survey be conducted to more accurately estimate the number of segments where savings could be realized and the anticipated wastewater treatment costs for those segments.

An across the board extension of the compliance date is not recommended, first because this would result in continued pollution with no economic advantages, and second because a three year delay could increase treatment costs in the same segments.

Specifically, it is recommended that EPA:

(1) Secure approval from Congress to grant compliance variances to those municipalities which can achieve significant cost reductions only through implementation of a water quality plan which cannot be completed prior to July 1, 1977.

(2) Institute a system whereby specific states are allowed extensions through the presentation of the documentation outlined previously.

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(3) Develop guidelines to be used by states in determining whether regionalization can lead to significant savings and whether or not a detailed basin study is justified.

(4) Establish the necessary administrative mechanisms within the Agency to process requests for variance.

(5) Secure the data necessary to prepare more certain estimates of potential savings at the national and state level.

# SECTION IX

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# SECTION X

## GLOSSARY

Advanced Waste Treatment (AWT)

Those methods which remove or reduce nutrients, residual organics, residual solids and pathogens by, but not limited to, sand filtration, chemical treatment, carbon absorption, ammonia stripping, electrodialysis or reverse osmosis.

Best Practicable Treatment (BPT)

That treatment level resulting from the application of the general average of the best existing control technology.

Best Available Treatment (BAT)

Generally the treatment level resulting from the application of the best existing control technology including technology which is capable of being designed though not yet in place.

Biological Oxygen Demand

The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. It is not related to the oxygen requirements in chemical combustion, being determined entirely by the availability of the material as biological food and by the amount of oxygen utilized by the microorganisms during oxidation. BOD is a frequently used measure of water quality.

Effluent Limited Segments

Those stream segments which meet instream water quality standards through the application of secondary level treatment to publicly-owned wastewater works and BPT to privately-owned wastewater works.

**Primary Treatment**

Those wastewater treatment plants that employ methods which remove or reduce a high percentage of the suspended and floating solids but little or no colloidal and dissolved matter.

**Secondary Treatment**

Those methods which remove or reduce fine suspended colloidal, dissolved solids, and cause the reduction of organic material by biological oxidation.

**Treatment Trains**

The combination of various unit processes and unit operations.

**Unit Processes**

Individual means of treatment in which the removal of contaminants is brought about by the addition of chemicals or biological activity.

**Unit Operations**

Individual means of treatment in which the application of physical forces predominate.

**Water Quality Limited Segments**

Those stream segments for which the application of effluent standards as specified in the 1972 FWPCAA does not achieve water quality standards. Treatment above the levels specified for effluent limited segments is required.

# SECTION XI

# APPENDICES

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# APPENDIX A

## Location and Description of Continuous-Dry Weather Discharges

### FOR CALUMET BASIN

| Discharge Designation | NPDES Permit Design. | Location (River Mile) | Description of Discharge |
|---|---|---|---|
| U.S. Steel | | East Branch | |
| GW-1 | | 9.30 | Process water from tube operation; non-contact water from coke plant. |
| GW-2 | | 9.20 | Non-contact water from distillation plant; misc. |
| GW-2A | | 9.08 | Process water from blast furnaces. |
| GW-3 | | 8.83 | Non-contact water from No. 1 battery air compressor; misc. |
| GW-3A | | 8.73 | Process water from blast furnaces. |
| GW-4 | | 8.50 | Non-contact water from No. 3 sinter plant. |
| GW-5 | | 8.35 | Process water from blast furnaces. |
| GW-6 | | 8.31 | Non-contact water from blast furnaces, No. 2 sinter plant, and No. 4 boiler house. |
| GW-7 | | 8.21 | Non-contact water from No. 2 sinter plant, No. 4 boiler house. |
| GW-7A | | 8.07 | Process water from No. 1 Basic Oxygen Process (BOP) shop and No. 4 boiler house. |
| GW-9 | | 7.94 | Non-contact water from No. 3 and No. 4 open hearth operations. |
| GW-10A | | 7.78 | Process water from bar mills, wheel mill, billet mill, rail mill, blooming mills, slabbing mill, and plate mill.<br>Non-contact water from bar mills and rail mill. |
| GW-11A | | 7.36 | Same as 10A. |
| GW-13 | | 7.30 | Non-contact water from bar mill. |

| Discharge Designation | NPDES Permit Design. | Location (River Mile) | Description of Discharge |
|---|---|---|---|
| ST-14 | | 6.50 | Non-contact water from atmosphere gas plant. |
| ST-17 | | 5.04 | Process water and non-contact water from galvanizing line hot strip mills, pickle lines, CR mills, CA lines, tin mills, and annealing operations. |
| Gary | | | |
| GSTP-1 | N/A | 4.60 | Gary's wastewater treatment facility discharge. |
| E.I. duPont | | | |
| 001 | 001 | 1.40 | Process and non-contact cooling water from the production of inorganic chemicals. |
| 002-004 | 002-004 | 1.38 | Same. |
| 005 | 005 | 1.16 | Same. |
| 007-010 | 007-010 | .85 | Same. |
| U.S.S. Refinery Inc. | | | |
| USL-1 | 001 | .25 | Non-contact cooling water discharge from blast furnace and casting mold. |
| Hammond | | | |
| HSTP-1 | N/A | West Branch 1.90 | Hammond's wastewater treatment facility discharge. |
| East Chicago | | | |
| ECSTP | N/A | .55 | East Chicago's wastewater treatment facility discharge. |

| Discharge Designation | NPDES Permit Design. | Location (River Mile) | Description of Discharge |
|---|---|---|---|
| Atlantic Richfield Oil Company | | Lake George Branch | |
| ARCO | 001 | 1.00 | Oil refinery discharge. |
| Union Carbide Linde Division | | IHS Canal | |
| UC-1 | 001 | 2.65 | Process and cooling discharge from production of industrial gases. |
| Youngstown | | | |
| YS-20 | 001 | 1.21 | Process water from continuous pickling, cold rolling and finishing operations. |
| American Steel Foundries | | | |
| AS-1 | 001 | 1.70 | Process and cooling waters from a foundry. |
| Inland | | | |
| IE-2 | 001 | 1.50 | Process and cooling water from an electric furnace steel shop and bar mill. |
| Youngstown | | | |
| YS-2 | 002 | 1.20 | Cooling water from cold rolling and finishing operations. |
| YS-4 | 003 | 1.16 | Cooling water from finishing operations at No. 1 tin mill. |
| YS-8 | 004 | 1.00 | Cooling water from cold rolling operation at No. 1 tin mill. |
| YS-11 | 005 | 1.00 | Cooling water from continuous pickling operation at No. 1 tin mill. |
| Inland | | | |
| 4E-1 | 002 | 1.00 | Process water, contact and non-contact cooling water from blast furnace; non-contact cooling water from a coke plant; and power house cooling water. |

| Discharge Designation | NPDES Permit Design. | Location (River Mile) | Description of Discharge |
|---|---|---|---|
| 5E-1 | 003 | .95 | Process water and non-contact cooling water from a plat mill, spike mill and continuous hot dip galvanizing li |
| 5E-2 | 004 | .94 | Process and non-contact cooling water from a spike mill |
| Youngstown | | | |
| YS-12 | 006 | .90 | Cooling and process water from a coke plant operation. |
| Inland | | | |
| 5E-3 | 005 | .87 | Process and non-contact cooling water from a bar mill a blooming mill. |
| Youngstown | | | |
| YS-13 | 007 | .83 | Cooling and process water from a coke plant operation. |
| Inland | | | |
| 6E-1 | 006 | .78 | Discharge from auto tunnel sump-pumps. |
| Youngstown | | | |
| YS-22 | 008 | .78 | Cooling and process water from a coke plant operation. |
| YS-14 | 009 | .65 | Power house and sinter plant cooling water. |
| Inland | | | |
| 7E-1 | 007 | .64 | Non-contact and contact cooling water from blast furnaces |
| Youngstown | | | |
| YS-15 | 010 | .63 | Power house and blast furnace cooling water. |
| Inland | | | |
| 10E-1 | 008 | .20 | Non-contact condenser cooling water from power house. |

| Discharge Designation | NPDES Permit Design. | Location (River Mile) | Description of Discharge |
|---|---|---|---|
| Youngstown | | | |
| YS-18A | 011 | Harbor<br>West Side | Process water and cooling water from blooming, hot strip, billet, bar, and buttweld mills; process and cooling water from boiler house, open hearths, and basic oxygen furnace; cooling water from blast furnace. |
| Inland | | | |
| 13G-1 | 011 | Harbor<br>East Side | Non-contact and contact cooling water from blast furnaces; non-contact cooling water from sintering plant and power house. |
| 13H-1 | 012 | Harbor<br>East Side | Gas scrubber water from blast furnaces, cooling water from coke plant and open hearth and a sanitary sewage plant effluent. |
| 14H-TT | 013 | Harbor<br>East Side | Process water from a coke plant, hot rolling mills, and cold rolling mills; coil picklers rinse water. |
| 15H-TT | 014 | Harbor<br>East Side | Process water from a coke plant, hot rolling mills, and cold rolling mills; coil picklers rinse water. |
| 16H-1 | 015 | Harbor<br>East Side | Non-contact cooling water from an open hearth furnace and a small sanitary sewage plant effluent. |
| 16H-2 | 016 | Harbor<br>East Side | Non-contact cooling water from an open hearth furnace and mold foundry operation. |
| 16H-3 | 017 | Harbor<br>East Side | Process water from hot and cold rolling mills. Non-contact cooling water from hot strip rolling mills, cold rolling mills, and coil picklers. |
| 16F-1 | 018 | Harbor<br>East Side | Grit water from basic oxygen furnace. Contact and non-contact cooling water from basic oxygen furnace; power house cooling water. |

Water Quality Standard 1.5 mg

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| U. S. Steel | | | | | | | | |
| GW-1 | 19.9 | 23.9 | 40.7 | 482.0 | | 2.0 | | |
| GW-2 | 10.9 | 16.4 | 23.0 | 274.0 | | 2.0 | | |
| GW-2A | 1.4 | 2.2 | 3.9 | 86.0 | | 4.7 | | |
| GW-3 | 2.7 | 3.8 | 4.5 | 38.0 | | 1.2 | | |
| GW-3A | 0.4 | 1.7 | 3.7 | 68.0 | | 4.8 | | |
| GW-4 | 0.5 | 0.7 | 0.9 | 0.5 | 1.5 | 0.1 | 0.2 | |
| GW-5 | 82.4 | 87.7 | 95.3 | 3510.0 | | 4.8 | | |
| GW-6 | 23.4 | 29.5 | 39.4 | 49.0 | 131.3 | 0.2 | 0.4 | |
| GW-7 | 5.8 | 10.6 | 16.9 | 17.6 | 56.4 | 0.2 | 0.4 | |
| GW-7A | 93.3 | 120.1 | 146.0 | 201.0 | 486.0 | 0.2 | 0.4 | |
| GW-9 | 24.7 | 34.7 | 39.7 | 57.6 | 132.1 | 0.2 | 0.4 | |
| GW-10A | 26.3 | 34.6 | 47.2 | 57.5 | 157.0 | 0.2 | 0.4 | |
| GW-11A | 81.3 | 94.7 | 115.6 | 158.0 | 385.0 | 0.2 | 0.4 | |
| GW-13 | 1.8 | 2.9 | 4.8 | 4.8 | 16.0 | 0.2 | 0.4 | |
| ST-14 | 0.8 | 1.8 | 3.3 | 3.0 | 11.0 | 0.2 | 0.4 | |
| ST-17 | 20.1 | 30.0 | 39.3 | 49.8 | 131.0 | 0.2 | 0.4 | |
| GSTP | 44.0 | 52.7 | 62.0 | 4080.0 | | 9.3 | | |
| E.I. duPont | | | | | | | | |
| 001 | 0.5 | 1.8 | 2.4 | 1240.0 | 1860.0 | 90.0 | 610.0 | |
| 002-004 | 7.24 | 10.31 | 11.66 | – | – | – | – | |
| 005 | 0.07 | 0.08 | 0.12 | .13 | .40 | 0.2 | 0.4 | |
| 006-010 | 0.89 | 2.24 | 2.98 | 3.74 | 9.96 | 0.2 | 0.4 | |
| U.S.S. Lead | | 0.36 | | – | – | – | – | |
| HSTP | 35.0 | 40.7 | 44.0 | 2480.0 | | 7.3 | | |
| ECSTP | 10.0 | 14.0 | 20.0 | 10,700 | 29,700 | 92.0 | 178.0 | 35% of the avg. load |
| Union Carbide | 0.05 | 0.07 | 0.11 | 0.41 | 1.1 | 0.7 | 1.2 | |
| ARCO | | 5.04 | 6.77 | 601.0 | 1,640 | 14.3 | 28.6 | |
| Amer. St. Foundries | 0.09 | 0.15 | 0.27 | .08 | .20 | 0.07 | 0.09 | |

## Inventory of Significant Continuous-Dry Weather Discharges (Continued)

$NH_3$ Water Quality Standard 1.5 mg/l

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| Youngstown | | | | | | | | |
| 001 YS-20 | 8.46 | 13.70 | 23.60 | 114.0 | 295.0 | 1.0 | 1.5 | |
| 002 YS-2 | 1.50 | 3.62 | 7.50 | 30.2 | 45.3 | 1.0 | 1.5 | |
| 003 YS-4 | 0.53 | 0.98 | 1.40 | 8.2 | 12.3 | 1.0 | 1.5 | |
| 004 YS-8 | 1.03 | 1.40 | 1.75 | 12.0 | 17.5 | 1.0 | 1.5 | |
| 005 YS-11 | 1.19 | 1.60 | 3.00 | 40.0 | 66.7 | 2.0 | 3.0 | |
| 006 YS-12 | 3.30 | 5.70 | 8.40 | 536.0 | 900.0 | 11.7 | 13.0 | |
| 007 YS-13 | 6.30 | 14.00 | 18.90 | 234.0 | 6,197.0 | 2.0 | 53.0 | |
| 008 YS-22 | 3.00 | 5.00 | 11.70 | 166.0 | 2,000.0 | 4.0 | 35.0 | |
| 009 YS-14 | 34.00 | 48.70 | 60.00 | 406.0 | 750.0 | 1.0 | 1.5 | |
| 010 YS-15 | 36.60 | 58.00 | 67.00 | 969.0 | 1,680.0 | 2.0 | 3.0 | |
| 011 YS-18A | 107.80 | 121.60 | 138.70 | 2,020.0 | 3,460.0 | 2.0 | 3.0 | |
| Inland | | | | | | | | |
| 001 1E-2 | | .14 | .29 | .23 | .97 | .2 | .4 | |
| 002 4E-1 | | 190.00 | 228.00 | 1,000.0 | 12,050.0 | .63 | 6.44 | |
| 003 5E-1 | | 7.20 | 8.60 | 12.0 | 28.6 | .2 | .4 | |
| 004 5E-2 | 8.60 | 0.86 | 1.04 | 1.4 | 3.5 | .23 | .4 | |
| 005 5E-3 | | 8.60 | 10.40 | 108.0 | 172.0 | 1.5 | 2.0 | |
| 006 6E-1 | | 0.65 | 1.30 | 1.1 | 4.3 | .2 | .4 | |
| 007 7E-1 | | 21.60 | 25.90 | 35.9 | 86.4 | .2 | .4 | |
| 008 10E-1 | Unknown & Highly Variable | | | | | | | |
| 011 13G-1 | 126.96 | 158.70 | 190.44 | 238.0 | 333.44 | .18 | .21 | |
| 012 13H-1 | 67.68 | 50.80 | 70.00 | 1,450.0 | 8,000.0 | 3.42 | 13.70 | |
| 013 14H-TT | 85.52 | 106.90 | 128.28 | 641.9 | 3,263.0 | .72 | 3.05 | |
| 014 15H-TT | 85.52 | 106.90 | 128.28 | 651.73 | 2,785.1 | .73 | 2.59 | |
| 015 16H-1 | 17.28 | 21.60 | 25.92 | 23.42 | 43.23 | .13 | .20 | |
| 016 16H-2 | 7.20 | 9.00 | 10.80 | 18.26 | 27.02 | .23 | .30 | |
| 017 16H-3 | 115.28 | 144.10 | 172.92 | 204.30 | 288.43 | .17 | .20 | |
| 018 16F-1 | 119.76 | 149.70 | 179.64 | 187.27 | 599.22 | .15 | .40 | |

## Iron

No Specific Water Quality Sta

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| U. S. Steel | | | | | | | | |
| GW-1 | 19.9 | 28.9 | 40.7 | 250.0 | 1211.0 | 1.05 | 5.1 | |
| GW-2 | 10.9 | 16.4 | 23.0 | 128.0 | 632.0 | .92 | 6.5 | |
| GW-2A | 1.4 | 2.2 | 3.9 | 86.0 | 238.0 | 4.15 | 12.0 | |
| GW-3 | 2.7 | 3.8 | 4.5 | 18.0 | 56.0 | .57 | 1.6 | |
| GW-3A | 0.4 | 1.7 | 3.7 | 36.0 | 119.0 | 2.70 | 6.2 | |
| GW-4 | 0.5 | 0.7 | 0.9 | 4.0 | 13.0 | .60 | 2.0 | |
| GW-5 | 82.4 | 87.7 | 95.3 | 1910.0 | 4939.0 | 2.50 | 6.7 | |
| GW-6 | 23.4 | 29.5 | 39.4 | 76.0 | 263.0 | .30 | 0.9 | |
| GW-7 | 5.8 | 10.6 | 16.9 | 52.0 | 455.0 | .55 | 5.2 | |
| GW-7A | 93.3 | 120.1 | 146.0 | 1013.0 | 9631.0 | .95 | 8.3 | |
| GW-9 | 24.7 | 34.7 | 39.7 | 197.0 | 2330.0 | .70 | 7.5 | |
| GW-10A | 26.3 | 34.6 | 47.2 | 346.0 | 1410.0 | 1.23 | 5.7 | |
| GW-11A | 81.3 | 94.7 | 115.6 | 975.0 | 3399.0 | 1.23 | 4.3 | |
| GW-13 | 1.8 | 2.9 | 4.8 | 33.0 | 186.0 | 1.97 | 10.5 | |
| ST-14 | 0.8 | 1.8 | 3.3 | 214.0 | 1799.0 | 14.00 | 120.0 | |
| ST-17 | 20.1 | 30.0 | 39.3 | 1290.0 | 6853.0 | 5.25 | 36.4 | |
| GSTP | 44.0 | 52.7 | 62.0 | 307.66 | 1964.90 | .70 | 3.8 | |
| E.I. duPont | | | | | | | | |
| 001 | 0.5 | 1.8 | 2.4 | – | | – | | |
| 002-004 | 7.24 | 10.31 | 11.66 | – | | – | | |
| 005 | 0.07 | 0.08 | 0.12 | – | | – | | |
| 006-010 | 0.89 | 2.24 | 2.98 | 3.7 | | .197 | | |
| U.S.S. Lead | | 0.36 | | – | – | – | – | |
| HSTP | 35.0 | 40.7 | 44.0 | 339.44 | 1688.02 | 1.00 | 4.6 | |
| ECSTP | 10.0 | 14.0 | 20.0 | 151.79 | 950.76 | 1.30 | 5.7 | |
| Union Carbide | 0.05 | 0.07 | 0.11 | | | – | | |
| ARCO | | 5.04 | 6.77 | 23.10 | 31.00 | .55 | .55 | |
| Amer. St. Foundries | 0.09 | 0.15 | 0.27 | 1.00 | | .80 | | |

Inventory of Significant Continuous-Dry Weather Discharges (Continued)

Iron — No Specific Water Quality Stand.

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| Youngstown | | | | | | | | |
| 001 YS-20 | 8.46 | 13.70 | 23.60 | 342.00 | 1476.18 | 3.0 | 7.5 | |
| 002 YS-2 | 1.50 | 3.62 | 7.50 | 39.25 | 312.75 | 1.3 | 5.0 | |
| 003 YS-4 | 0.53 | 0.98 | 1.40 | 6.54 | | 0.8 | | |
| 004 YS-8 | 1.03 | 1.40 | 1.75 | 100.41 | 1313.55 | 8.6 | 90.0 | |
| 005 YS-11 | 1.19 | 1.60 | 3.00 | 190.82 | 1125.90 | 14.3 | 45.0 | |
| 006 YS-12 | 3.30 | 5.70 | 8.40 | 85.57 | | 1.8 | | |
| 007 YS-13 | 6.30 | 14.00 | 18.90 | 116.76 | | 1.0 | | |
| 008 YS-22 | 3.00 | 5.00 | 11.70 | 41.70 | | 1.0 | | |
| 009 YS-14 | 34.00 | 48.70 | 60.00 | 243.69 | | 0.6 | | |
| 010 YS-15 | 36.60 | 58.00 | 67.00 | 773.95 | | 1.6 | | |
| 011 YS-18A | 107.80 | 121.60 | 138.70 | 2523.00 | 10,360.0 | 2.5 | 9.0 | |
| Inland | | | | | | | | |
| 001 IE-2 | | .14 | .29 | 1.34 | 8.71 | 1.15 | 3.60 | |
| 002 4E-1 | | 190.00 | 228.00 | 475.38 | 847.68 | 0.30 | 0.45 | |
| 003 5E-1 | | 7.20 | 8.60 | 147.72 | 2[illegible]4.07 | 2.46 | 4.10 | |
| 004 5E-2 | 8.60 | 0.86 | 1.04 | 14.34 | 60.71 | 2.00 | 7.00 | |
| 005 5E-3 | | 8.60 | 10.40 | 156.00 | 229.85 | 2.175 | 2.65 | |
| 006 6E-1 | | 0.65 | 1.30 | 2.17 | 6.50 | 0.40 | 0.60 | |
| 007 7E-1 | | 21.60 | 25.90 | 5.61 | 162.00 | 0.673 | 0.75 | |
| 008 10E-1 | Unknown & Highly Variable | | | | | | | |
| 011 13G-1 | 126.96 | 158.70 | 190.44 | 430.00 | 1,210.0 | 0.325 | 0.50 | |
| 012 13H-1 | 67.68 | 50.80 | 70.00 | 212.00 | 467.0 | 0.500 | 0.80 | |
| 013 14H-TT | 85.52 | 106.90 | 128.28 | 3,120.00 | 18,000.0 | 3.500 | 16.80 | |
| 014 15H-TT | 85.52 | 106.90 | 128.28 | 2,670.00 | 18,750.0 | 3.000 | 17.50 | |
| 015 16H-1 | 17.28 | 21.60 | 25.92 | 43.00 | 65.0 | 0.239 | 0.30 | |
| 016 16H-2 | 7.20 | 9.00 | 10.80 | 21.70 | 45.0 | 0.290 | 0.50 | |
| 017 16H-3 | 115.26 | 144.10 | 172.92 | 385.00 | 1,057.0 | 0.737 | 0.88 | |
| 018 16F-1 | 119.76 | 149.70 | 179.64 | 2,240.00 | 23,960.0 | 1.800 | 19.20 | |

## entory of Significant Continuous-Dry Weather Discharges

Suspended Solids

No Specific Water Quality Stan

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| U. S. Steel | | | | | | | | |
| GW-1 | 19.9 | 28.9 | 40.7 | 5,390 | 20,892 | 24.0 | 88 | |
| GW-2 | 10.9 | 16.4 | 23.0 | 3,320 | 45,962 | 25.0 | 363 | |
| GW-2A | 1.4 | 2.2 | 3.9 | 738 | 72,832 | 39.5 | 148 | |
| GW-3 | 2.7 | 3.8 | 4.5 | 428 | 1,784 | 14.3 | 51 | |
| GW-3A | 0.4 | 1.7 | 3.7 | 494 | 2,184 | 33.2 | 114 | |
| GW-4 | 0.5 | 0.7 | 0.9 | 123 | 322 | 18.2 | 43 | |
| GW-5 | 82.4 | 87.7 | 95.3 | 21,350 | 57,951 | 30.0 | 73 | |
| GW-6 | 23.4 | 29.5 | 39.4 | 3,130 | 11,495 | 13.0 | 46 | |
| GW-7 | 5.8 | 10.6 | 16.9 | 2,210 | 6,560 | 24.0 | 75 | |
| GW-7A | 93.3 | 120.1 | 146.0 | 12,450 | 243,677 | 11.0 | 210 | |
| GW-9 | 24.7 | 34.7 | 39.7 | 4,870 | 14,619 | 17.0 | 50 | |
| GW-10A | 26.3 | 34.6 | 47.2 | 8,270 | 19,545 | 29.0 | 79 | |
| GW-11A | 81.3 | 94.7 | 115.6 | 19,750 | 64,032 | 25.0 | 81 | |
| GW-13 | 1.8 | 2.9 | 4.8 | 304 | 795 | 17.0 | 53 | |
| ST-14 | 0.8 | 1.8 | 3.3 | 813 | 8,592 | 52.0 | 573 | |
| ST-17 | 20.1 | 30.0 | 39.3 | 7,970 | 32,759 | 32.0 | 106 | |
| GSTP | 44.0 | 52.7 | 62.0 | 24,000 | 162,600 | 54.4 | 314 | |
| E.I. duPont | | | | | | | | |
| 001 | 0.5 | 1.8 | 2.4 | 1,300 | 500 | 40.0 | | |
| 002-004 | 7.24 | 10.31 | 11.66 | 13 | 25 | | | |
| 005 | 0.07 | 0.08 | 0.12 | - | - | - | - | |
| 006-010 | 0.89 | 2.24 | 2.98 | 1,025 | 3,670 | 55.0 | 147 | |
| .S.S. Lead | | 0.36 | | - | - | - | - | |
| HSTP | 35.0 | 40.7 | 44.0 | 4,920 | 42,300 | 14.5 | 115 | |
| ECSTP | 10.0 | 14.0 | 20.0 | 4,820 | 31,100 | 41.3 | 186 | |
| nion Carbide | 0.05 | 0.07 | 0.11 | 9 | 46 | 21.0 | 50 | |
| ARCO | | 5.04 | 6.77 | 1,202 | 3,225 | 28.6 | 57.1 | |
| Amer. St. Foundries | 0.09 | 0.15 | 0.27 | 2.5 | 9 | 2.0 | 4 | |

Weather Discharges (Continued)

Suspended Solids

No Specific Water Quality Stan

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| Youngstown | | | | | | | | |
| 001 YS-20 | 8.46 | 13.70 | 23.60 | 1,750 | 35,900 | 15.3 | 182 | ** |
| 002 YS-2 | 1.50 | 3.62 | 7.50 | 118 | 1,000 | 3.9 | 16 | ** |
| 003 YS-4 | 0.53 | 0.98 | 1.40 | 155 | 1,342 | 19.0 | 115 | |
| 004 YS-8 | 1.03 | 1.40 | 1.75 | 102 | 438 | 8.7 | 30 | ** |
| 005 YS-11 | 1.19 | 1.60 | 3.00 | 114 | 1,780 | 8.5 | 71 | ** |
| 006 YS-12 | 3.30 | 5.70 | 8.40 | 1,190 | 4,910 | 25.0 | 90 | ** |
| 007 YS-13 | 6.30 | 14.00 | 18.90 | 818 | 3,154 | 7.0 | 20 | |
| 008 YS-22 | 3.00 | 5.00 | 11.70 | 446 | 3,420 | 10.7 | 35 | ** |
| 009 YS-14 | 34.00 | 48.70 | 60.00 | 175 | 551 | 4.3 | 11 | ** |
| 010 YS-15 | 36.60 | 58.00 | 67.00 | 28,010 | 128,800 | 57.0 | 230 | ** |
| 011 YS-18A | 107.80 | 121.60 | 138.70 | 20,250 | 84,400 | 20.0 | 73 | |
| Inland | | | | | | | | |
| 001 IE-2 | | .14 | .29 | 23 | 121 | 19.3 | 50 | |
| 002 4E-1 | | 190.00 | 228.00 | 29,200 | 123,800 | 18.4 | 65 | |
| 003 5E-1 | | 7.20 | 8.60 | 1,573 | 7,170 | 26.2 | 100 | |
| 004 5E-2 | 8.60 | 0.86 | 1.04 | 192 | 877 | 26.7 | 100 | |
| 005 5E-3 | | 8.60 | 10.40 | 1,830 | 8,240 | 25.5 | 95 | |
| 006 6E-1 | | 0.65 | 1.30 | 54 | 434 | 10.0 | 40 | |
| 007 7E-1 | | 21.60 | 25.90 | 3,640 | 15,120 | 20.2 | 70 | |
| 008 10E-1 | Unknown & Highly Variable | | | | | | | |
| 011 13G-1 | 126.96 | 158.70 | 190.44 | 29,118.28 | 141355.99 | 22.0 | 89 | |
| 012 13H-1 | 67.68 | 50.80 | 70.00 | 8,897.11 | 33276.6 | 21.0 | 57 | |
| 013 14H-TT | 85.52 | 106.90 | 128.28 | 25,854.83 | 115544.36 | 29.0 | 108 | |
| 014 15H-TT | 85.52 | 106.90 | 128.28 | 20,505.56 | 77029.57 | 23.0 | 72 | |
| 015 16H-1 | 17.28 | 21.60 | 25.92 | 540.43 | 1080.86 | 3.0 | 5 | |
| 016 16H-2 | 7.20 | 9.00 | 10.80 | 825.66 | 8646.91 | 11.0 | 96 | |
| 017 16H-3 | 115.28 | 144.10 | 172.92 | 28,843.06 | 134120.21 | 24.0 | 93 | |
| 018 16F-1 | 119.76 | 149.70 | 179.64 | 21,224.47 | 89391.86 | 17.0 | 60 | |

** Net value - add 8 mg/l for total.

# Inventory of Significant Continuous-Dry Weather Discharges

## Chlorides

Water Quality Standard 35 mg/l

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| U. S. Steel | | | | | | | | |
| GW-1 | 19.9 | 28.9 | 40.7 | 2,660 | 5,080 | 11 | 15 | |
| GW-2 | 10.9 | 16.4 | 23.0 | 1,913 | 3,260 | 14 | 17 | |
| GW-2A | 1.4 | 2.2 | 3.9 | 366 | 876 | 20 | 27 | |
| GW-3 | 2.7 | 3.8 | 4.5 | 444 | 939 | 14 | 25 | |
| GW-3A | 0.4 | 1.7 | 3.7 | 312 | 895 | 22 | 29 | |
| GW-4 | 0.5 | 0.7 | 0.9 | 58 | 114 | 10 | 15 | |
| GW-5 | 82.4 | 87.7 | 95.3 | 15,380 | 23,100 | 21 | 29 | |
| GW-6 | 23.4 | 29.5 | 39.4 | 2,460 | 4,940 | 10 | 15 | |
| GW-7 | 5.8 | 10.6 | 16.9 | 2,210 | 4,510 | 25 | 32 | |
| GW-7A | 93.3 | 120.1 | 146.0 | 12,010 | 19,450 | 12 | 16 | |
| GW-9 | 24.7 | 34.7 | 39.7 | 4,930 | 8,280 | 17 | 25 | |
| GW-10A | 26.3 | 34.6 | 47.2 | 4,910 | 10,610 | 17 | 27 | |
| GW-11A | 81.3 | 94.7 | 115.6 | 11,870 | 19,270 | 15 | 20 | |
| GW-13 | 1.8 | 2.9 | 4.8 | 290 | 695 | 12 | 17 | |
| ST-14 | 0.8 | 1.8 | 3.3 | 710 | 6,500 | 50 | 236 | |
| ST-17 | 20.1 | 30.0 | 39.3 | 21,200 | 39,300 | 85 | 120 | |
| C TP | 44.0 | 52.7 | 62.0 | 29,500 | 51,600 | 67 | 100 | |
| E.I. duPont | | | | | | | | |
| 001 | 0.5 | 1.8 | 2.4 | 4,100 | 8,700 | 280 | 2,230 | |
| 002-004 | 7.24 | 10.31 | 11.66 | 0 | 0 | - | - | |
| 005 | 0.07 | 0.08 | 0.12 | 600 | 2,000 | 910 | 3,330 | |
| 006-010 | 0.89 | 2.24 | 2.98 | 300 | 1,000 | 161 | 403 | |
| U.S.S. Lead | | 0.36 | | 86 | 273 | 28.5 | 91 | |
| HSTP | 35.0 | 40.7 | 44.0 | 40,700 | 73,400 | 120 | 200 | |
| ECSTP | 10.0 | 14.0 | 20.0 | 41,600 | 102,800 | 356 | 675 | |
| Union Carbide | 0.05 | 0.07 | 0.11 | 6 | 14 | 10 | 15 | |
| ARCO | | 5.04 | 6.77 | 12,600 | 25,400 | 300 | 450 | |
| er. St. Foundries | 0.09 | 0.15 | 0.27 | 1,350 | 3,380 | 1,080 | 1,500 | |

## Inventory of Significant Continuous-Dry Weather Discharges (Continued)

Chlorides — Water Quality Standard 35 mg/

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| Youngstown | | | | | | | | |
| 001 YS-20 | 8.46 | 13.70 | 23.60 | 2,284 | 5,900 | 20 | 30 | |
| 002 YS-2 | 1.50 | 3.62 | 7.50 | 452 | 1,560 | 15 | 25 | |
| 003 YS-4 | 0.53 | 0.98 | 1.40 | 317 | 475 | 28 | 42 | |
| 004 YS-8 | 1.03 | 1.40 | 1.75 | 140 | 278 | 12 | 19 | |
| 005 YS-11 | 1.19 | 1.60 | 3.00 | 294 | 750 | 22 | 30 | |
| 006 YS-12 | 3.30 | 5.70 | 8.40 | 2,420 | 7,210 | 51 | 103 | Monthly re data |
| 007 YS-13 | 6.30 | 14.00 | 18.90 | 4,326 | 26,638 | 37 | 169 | |
| 008 YS-22 | 3.00 | 5.00 | 11.70 | 1,405 | 72,440 | 29 | 1,495 | |
| 009 YS-14 | 34.00 | 48.70 | 60.00 | 6,090 | 10,000 | 15 | 20 | |
| 010 YS-15 | 36.60 | 58.00 | 67.00 | 12,080 | 16,740 | 25 | 30 | |
| 011 YS-18A | 107.80 | 121.60 | 138.70 | 21,291 | 32,444 | 21 | 32 | |
| Inland | | | | | | | | |
| 001 IE-2 | | .14 | .29 | 30 | 249 | 26 | 103 | |
| 002 4E-1 | | 190.00 | 228.00 | 25,340 | 57,000 | 16 | 30 | |
| 003 5E-1 | | 7.20 | 8.60 | 2,380 | 3,730 | 39 | 52 | P. data hi of 67 |
| 004 5E-2 | 8.60 | 0.86 | 1.04 | 86 | 156 | 12 | 18 | |
| 005 5E-3 | | 8.60 | 10.40 | 788 | 1,560 | 11 | 18 | |
| 006 6E-1 | | 0.65 | 1.30 | 135 | 282 | 25 | 26 | |
| 007 7E-1 | | 21.60 | 25.90 | 2,160 | 3,240 | 12 | 15 | |
| 008 10E-1 | Unknown & Highly Variable | | | | | | | |
| 011 13G-1 | 126.96 | 158.70 | 190.44 | 17,200 | 19,800 | 13 | 15 | |
| 012 13H-1 | 67.68 | 50.80 | 70.00 | 16,099.54 | 39,698.4 | 38 | 68 | |
| 013 14H-TT | 85.52 | 106.90 | 128.28 | 16,000 | 32,095.65 | 18 | 30 | |
| 014 15H-TT | 85.52 | 106.90 | 128.28 | 16,000 | 36,375.08 | 18 | 34 | High recorded in Jan. |
| 015 16H-1 | 17.28 | 21.60 | 25.92 | 2,520 | 2,700 | 14 | 15 | |
| 016 16H-2 | 7.20 | 9.00 | 10.80 | 1,050 | 1,500 | 14 | 20 | |
| 017 16H-3 | 115.28 | 144.10 | 172.92 | 14,400 | 18,000 | 12 | 15 | |
| 018 16F-1 | 119.76 | 149.70 | 179.64 | 13,730 | 23,971.16 | 11 | 16 | |

## Significant Continuous-Dry Weather Discharges

### Cyanide

Water Quality Standard .1 mg/

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| U. S. Steel | | | | | | | | |
| GW-1 | 19.9 | 28.9 | 40.7 | 2.41 | 33.90 | .01 | .10 | |
| GW-2 | 10.9 | 16.4 | 23.0 | 2.72 | 19.20 | .02 | .10 | |
| GW-2A | 1.4 | 2.2 | 3.9 | 55.00 | 130.00 | 3.00 | 4.00 | |
| GW-3 | 2.7 | 3.8 | 4.5 | 3.17 | 8.25 | .10 | .22 | |
| GW-3A | 0.4 | 1.7 | 3.7 | 42.50 | 123.50 | 3.00 | 4.00 | |
| GW-4 | 0.5 | 0.7 | 0.9 | .06 | .15 | .01 | .020 | |
| GW-5 | 82.4 | 87.7 | 95.3 | 2925.00 | 4860.00 | 4.00 | 6.10 | |
| GW-6 | 23.4 | 29.5 | 39.4 | 2.46 | 6.57 | .01 | .02 | |
| GW-7 | 5.8 | 10.6 | 16.9 | .88 | 169.00 | .01 | 1.20 | P. data |
| GW-7A | 93.3 | 120.1 | 146.0 | 10.01 | 60.70 | .01 | .05 | |
| GW-9 | 24.7 | 34.7 | 39.7 | 2.88 | 6.61 | .01 | .02 | |
| GW-10A | 26.3 | 34.6 | 47.2 | 14.45 | 31.50 | .05 | .08 | P. data |
| GW-11A | 81.3 | 94.7 | 115.6 | 39.40 | 77.10 | .05 | .08 | P. data |
| GW-13 | 1.8 | 2.9 | 4.8 | .12 | .80 | .005 | .020 | |
| ST-14 | 0.8 | 1.8 | 3.3 | .15 | | .010 | | P. data |
| ST-17 | 20.1 | 30.0 | 39.3 | 2.50 | | .010 | | |
| GSTP | 44.0 | 52.7 | 62.0 | 22.00 | 46.40 | .05 | .09 | |
| E.I. duPont | | | | | | | | |
| 001 | 0.5 | 1.8 | 2.4 | .15 | .40 | .010 | .020 | |
| 002-004 | 7.24 | 10.31 | 11.66 | – | – | | | |
| 005 | 0.07 | 0.08 | 0.12 | .01 | .02 | .010 | .020 | |
| 006-010 | 0.89 | 2.24 | 2.98 | | | .010 | .020 | |
| .S.S. Lead | | 0.36 | | .30 | .60 | .010 | .010 | |
| HSTP | 35.0 | 40.7 | 44.0 | 17.00 | 33.00 | .050 | .090 | |
| ECSTP | 10.0 | 14.0 | 20.0 | 57.20 | 300.00 | .490 | 1.800 | |
| nion Carbide | 0.05 | 0.07 | 0.11 | .01 | .02 | .010 | .200 | |
| ARCO | | 5.04 | 6.77 | 4.00 | 11.00 | .100 | .200 | |
| Amer. St. Foundries | 0.09 | 0.15 | 0.27 | .01 | .04 | .010 | .020 | |

## Inventory of Significant Continuous-Dry Weather Discharges (Continued)

### Cyanide

Water Quality Standard .1

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| Youngstown | | | | | | | | |
| 001 YS-20 | 8.46 | 13.70 | 23.60 | 1.00 | 94.00 | .010 | .480 | |
| 002 YS-2 | 1.50 | 3.62 | 7.50 | .30 | 1.25 | .010 | .020 | |
| 003 YS-4 | 0.53 | 0.98 | 1.40 | .08 | .23 | .010 | .020 | |
| 004 YS-8 | 1.03 | 1.40 | 1.75 | .12 | .31 | .010 | .020 | |
| 005 YS-11 | 1.19 | 1.60 | 3.00 | .13 | .50 | .010 | .020 | |
| 006 YS-12 | 3.30 | 5.70 | 8.40 | 927.00 | 1453.00 | 17.800 | 31.700 | |
| 007 YS-13 | 6.30 | 14.00 | 18.90 | 4.67 | 9.45 | .040 | .060 | |
| 008 YS-22 | 3.00 | 5.00 | 11.70 | 1.25 | 4.86 | .030 | .050 | Net effec |
| 009 YS-14 | 34.00 | 48.70 | 60.00 | 4.06 | 10.00 | .010 | .020 | |
| 010 YS-15 | 36.60 | 58.00 | 67.00 | 38.60 | 55.90 | .080 | .100 | Net effect |
| 011 YS-18A | 107.80 | 121.60 | 138.70 | 91.00 | 300.00 | .090 | .260 | |
| Inland | | | | | | | | |
| 001 IE-2 | | .14 | .29 | .01 | .05 | .010 | .020 | |
| 002 4E-1 | | 190.00 | 228.00 | 934.00 | 3209.00 | .590 | 2.080 | |
| 003 5E-1 | | 7.20 | 8.60 | .60 | 1.44 | .010 | .020 | |
| 004 5E-2 | 8.60 | 0.86 | 1.04 | .07 | .17 | .010 | .020 | |
| 005 5E-3 | | 8.60 | 10.40 | .72 | 1.73 | .010 | .020 | |
| 006 6E-1 | | 0.65 | 1.30 | 10.60 | | 1.950 | | Permits |
| 007 7E-1 | | 21.60 | 25.90 | 98.20 | 542.00 | .560 | 2.510 | |
| 008 10E-1 | Unknown & Highly Variable | | | | | | | |
| 011 13G-1 | 126.96 | 158.70 | 190.44 | 119.00 | 582.00 | .090 | .440 | 24 hr. sample |
| 012 13H-1 | 67.68 | 50.80 | 70.00 | 55.10 | 338.60 | .130 | .580 | 1.16 |
| 013 14H-TT | 85.52 | 106.90 | 128.28 | 44.50 | 278.16 | .050 | .260 | 24 hr. sample<br>.542 |
| 014 15H-TT | 85.52 | 106.90 | 128.28 | 44.50 | 342.35 | .050 | .320 | |
| 015 16H-1 | 17.28 | 21.60 | 25.92 | .18 | .22 | .001 | .001 | |
| 016 16H-2 | 7.20 | 9.00 | 10.80 | .07 | .09 | .001 | .001 | |
| 017 16H-3 | 115.28 | 144.10 | 172.92 | 1.20 | 1.44 | .001 | .001 | |
| 018 16F-1 | 119.76 | 149.70 | 179.64 | 1.25 | 1.50 | .001 | .001 | |

## Phenols

Water Quality Standard .01

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| U. S. Steel | | | | | | | | |
| GW-1 | 19.9 | 28.9 | 40.7 | 4.82 | 10.18 | .020 | .030 | |
| GW-2 | 10.9 | 16.4 | 23.0 | 17.80 | 30.30 | .130 | .158 | |
| GW-2A | 1.4 | 2.2 | 3.9 | 1.84 | 15.30 | .100 | .470 | |
| GW-3 | 2.7 | 3.8 | 4.5 | 2.30 | 2.66 | .064 | .071 | |
| GW-3A | 0.4 | 1.7 | 3.7 | .42 | 5.61 | .030 | .182 | |
| GW-4 | 0.5 | 0.7 | 0.9 | .01 | .01 | .001 | .001 | |
| GW-5 | 82.4 | 87.7 | 95.3 | 234.50 | 302.00 | .320 | .380 | |
| GW-6 | 23.4 | 29.5 | 39.4 | 1.47 | 2.63 | .006 | .008 | |
| GW-7 | 5.8 | 10.6 | 16.9 | .44 | 2.68 | .005 | .019 | |
| GW-7A | 93.3 | 120.1 | 146.0 | 35.10 | 51.18 | .035 | .042 | |
| GW-9 | 24.7 | 34.7 | 39.7 | .58 | 2.64 | .002 | .008 | |
| GW-10A | 26.3 | 34.6 | 47.2 | 1.13 | 3.94 | .004 | .010 | |
| GW-11A | 81.3 | 94.7 | 115.6 | 1.58 | 2.89 | .002 | .003 | |
| GW-13 | 1.8 | 2.9 | 4.8 | .24 | .48 | .010 | .012 | |
| ST-14 | 0.8 | 1.8 | 3.3 | .01 | .01 | .001 | .001 | |
| ST-17 | 20.1 | 30.0 | 39.3 | 22.45 | 47.85 | .090 | .146 | |
| GSTP | 44.0 | 52.7 | 62.0 | 1.76 | 5.16 | .004 | .010 | |
| E.I. duPont | | | | | | | | |
| 001 | 0.5 | 1.8 | 2.4 | .01 | .01 | .001 | .001 | |
| 002-004 | 7.24 | 10.31 | 11.66 | .10 | .12 | .001 | .001 | |
| 005 | 0.07 | 0.08 | 0.12 | – | – | .001 | .001 | |
| 006-010 | 0.89 | 2.24 | 2.98 | .01 | .01 | .001 | .001 | |
| U.S.S. Lead | | 0.36 | | – | – | – | – | |
| HSTP | 35.0 | 40.7 | 44.0 | 1.47 | 3.67 | .004 | .010 | |
| ECSTP | 10.0 | 14.0 | 20.0 | 18.58 | 432.00 | .159 | 2.590 | |
| Union Carbide | 0.05 | 0.07 | 0.11 | – | – | .001 | .001 | |
| ARCO | | 5.04 | 6.77 | 2.90 | 3.06 | .070 | .143 | |
| Amer. St. Foundries | 0.09 | 0.15 | 0.27 | .02 | .11 | .003 | .005 | |

## Inventory of Significant Continuous-Dry Weather Discharges (Continued)

Phenols — Water Quality Standard .01 mg/1

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/1) | Max. Conc. (mg/1) | Comments |
|---|---|---|---|---|---|---|---|---|
| Youngstown | | | | | | | | |
| 001 YS-20 | 8.46 | 13.70 | 23.60 | 1.14 | 3.06 | .010 | .015 | |
| 002 YS-2 | 1.50 | 3.62 | 7.50 | .03 | .06 | .001 | .001 | |
| 003 YS-4 | 0.53 | 0.98 | 1.40 | .01 | .01 | .001 | .001 | |
| 004 YS-8 | 1.03 | 1.40 | 1.75 | .01 | .01 | .001 | .001 | |
| 005 YS-11 | 1.19 | 1.60 | 3.00 | .01 | .02 | .001 | .001 | |
| 006 YS-12 | 3.30 | 5.70 | 8.40 | 69.30 | 114.00 | 1.520 | 2.480 | |
| 007 YS-13 | 6.30 | 14.00 | 18.90 | 303.00 | 3040.00 | 2.590 | 26.000 | |
| 008 YS-22 | 3.00 | 5.00 | 11.70 | 14.10 | 606.00 | .290 | 12.500 | |
| 009 YS-14 | 34.00 | 48.70 | 60.00 | .41 | .51 | .001 | .001 | |
| 010 YS-15 | 36.60 | 58.00 | 67.00 | 8.23 | 12.77 | .017 | .023 | |
| 011 YS-18A | 107.80 | 121.60 | 138.70 | 11.20 | 17.20 | .011 | .017 | |
| Inland | | | | | | | | |
| 001 1E-2 | | .14 | .29 | – | – | .001 | .001 | |
| 002 4E-1 | | 190.00 | 228.00 | 17.40 | 179.00 | .011 | .094 | |
| 003 5E-1 | | 7.20 | 8.60 | .06 | .07 | .001 | .001 | |
| 004 5E-2 | 8.60 | 0.86 | 1.04 | .01 | .01 | .001 | .001 | |
| 005 5E-3 | | 3.60 | 10.40 | .07 | .09 | .001 | .001 | |
| 006 6E-1 | | 0.65 | 1.30 | .01 | .01 | .001 | .001 | |
| 007 7E-1 | | 21.60 | 25.90 | 6.32 | 8.21 | .035 | .038 | |
| 008 10E-1 | Unknown & Highly Variable | | | | | | | |
| 011 13G-1 | 126.96 | 158.70 | 190.44 | 10.00 | 16.00 | .008 | .012 | |
| 012 13H-1 | 67.68 | 50.80 | 70.00 | 29.60 | 432.01 | .070 | .740 | |
| 013 14H-TT | 85.52 | 106.90 | 128.28 | 51.60 | 532.93 | .058 | .500 | |
| 014 15H-TT | 85.52 | 106.90 | 128.28 | 57.00 | 748.90 | .064 | .700 | |
| 015 16H-1 | 17.28 | 21.60 | 25.92 | .18 | .22 | .001 | .001 | |
| 016 16H-2 | 7.20 | 9.00 | 10.80 | .07 | .09 | .001 | .001 | |
| 017 16H-3 | 115.28 | 144.10 | 172.92 | 1.20 | 1.44 | .001 | .001 | |
| 018 16F-1 | 119.76 | 149.70 | 179.64 | 1.25 | 1.50 | .001 | .001 | |

## Fluorides

Water Quality Standard 1.3 m

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| U. S. Steel | | | | | | | | |
| GW-1 | 19.9 | 28.9 | 40.7 | 36.15 | 67.89 | .15 | .20 | |
| GW-2 | 10.9 | 16.4 | 23.0 | 41.03 | 67.14 | .30 | .35 | |
| GW-2A | 1.4 | 2.2 | 3.9 | 31.19 | 65.05 | 1.70 | 2.00 | |
| GW-3 | 2.7 | 3.8 | 4.5 | 7.92 | 11.26 | .25 | .30 | |
| GW-3A | 0.4 | 1.7 | 3.7 | 24.10 | 58.63 | 1.70 | 1.90 | |
| GW-4 | 0.5 | 0.7 | 0.9 | .58 | .75 | .10 | .10 | |
| GW-5 | 82.4 | 87.7 | 95.3 | 1060.56 | 1351.16 | 1.45 | 1.70 | |
| GW-6 | 23.4 | 29.5 | 39.4 | 49.21 | 98.58 | .20 | .30 | |
| GW-7 | 5.8 | 10.6 | 16.9 | 22.10 | 49.33 | .25 | .35 | |
| GW-7A | 93.3 | 120.1 | 146.0 | 150.25 | 242.53 | .15 | .20 | |
| GW-9 | 24.7 | 34.7 | 39.7 | 57.88 | 72.77 | .20 | .25 | |
| GW-10A | 26.3 | 34.6 | 47.2 | 317.42 | 551.11 | 1.10 | 1.40 | |
| GW-11A | 81.3 | 94.7 | 115.6 | 394.90 | 675.82 | .50 | .70 | |
| GW-13 | 1.8 | 2.9 | 4.8 | 3.63 | 10.01 | .15 | .25 | |
| ST-14 | 0.8 | 1.8 | 3.3 | 4.50 | 11.01 | .30 | .40 | |
| ST-17 | 20.1 | 30.0 | 39.3 | 1200.96 | 1802.69 | 4.80 | 5.50 | |
| GSTP | 44.0 | 52.7 | 62.0 | 43.95 | 103.42 | .10 | .20 | |
| E.I. duPont | | | | | | | | |
| 001 | 0.5 | 1.8 | 2.4 | 24.00 | | 2.0 | | |
| 002-004 | 7.24 | 10.31 | 11.66 | - | | - | | |
| 005 | 0.07 | 0.08 | 0.12 | - | | - | | |
| 006-010 | 0.89 | 2.24 | 2.98 | - | | - | | |
| U.S.S. Lead | | 0.36 | | 5.6 | | | | |
| HSTP | 35.0 | 40.7 | 44.0 | 441.0 | | 1.85 | 49.70 | Sept. 72 |
| ECSTP | 10.0 | 14.0 | 20.0 | 170.0 | | 1.30<br>1.45 | | Grab sample<br>Grab sample |
| nion Carbide | 0.05 | 0.07 | 0.11 | - | | - | | |
| ARCO | | 5.04 | 6.77 | 21.85 | 48.55 | .52 | .86 | |
| Amer. St. Foundries | 0.09 | 0.15 | 0.27 | - | | - | | |

## Inventory of Significant Continuous-Dry Weather Discharges (Continued)

**Fluorides** Water Quality Standard 1.3 mg/l

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| Youngstown | | | | | | | | Intake .3 |
| 001 YS-20 | 8.46 | 13.70 | 23.60 | 86.84 | 236.19 | .76 | 1.2 | |
| 002 YS-2 | 1.50 | 3.62 | 7.50 | 12.08 | | .40 | | |
| 003 YS-4 | 0.53 | 0.98 | 1.40 | 4.74 | 9.92 | .58 | .85 | |
| 004 YS-8 | 1.03 | 1.40 | 1.75 | 4.67 | | .40 | | |
| 005 YS-11 | 1.19 | 1.60 | 3.00 | 5.34 | | .40 | | |
| 006 YS-12 | 3.30 | 5.70 | 8.40 | 14.26 | | .30 | | |
| 007 YS-13 | 6.30 | 14.00 | 18.90 | 35.03 | | .30 | | |
| 008 YS-22 | 3.00 | 5.00 | 11.70 | 12.51 | | .30 | | |
| 009 YS-14 | 34.00 | 48.70 | 60.00 | 121.84 | | .30 | | |
| 010 YS-15 | 36.60 | 58.00 | 67.00 | 290.23 | | .60 | | |
| 011 YS-18A | 107.80 | 121.60 | 138.70 | 760.00 | 1146.0 | .75 | 1.13 | |
| Inland | | | | | | | | |
| 001 1E-2 | | .14 | .29 | .35 | 1.45 | .30 | .60 | |
| 002 4E-1 | | 190.00 | 228.00 | 221.84 | 382.30 | .14 | .20 | |
| 003 5E-1 | | 7.20 | 8.60 | 12.01 | 28.69 | .20 | .40 | |
| 004 5E-2 | 8.60 | 0.86 | 1.04 | .43 | .87 | .06 | .10 | |
| 005 5E-3 | | 8.60 | 10.40 | 28.69 | | .40 | | 24 hr. sam<br>P says 0 |
| 006 6E-1 | | 0.65 | 1.30 | 1.62 | 4.77 | .29 | .43 | |
| 007 7E-1 | | 21.60 | 25.90 | 2.60 | 10.80 | .02 | .05 | |
| 008 10E-1 | Unknown & Highly Variable | | | | | | | |
| 011 13G-1 | 126.96 | 158.70 | 190.44 | 172.06 | 317.60 | .13 | .20 | |
| 012 13H-1 | 67.68 | 50.80 | 70.00 | 143.95 | 1401.12 | .34 | 2.40 | Max. is<br>24 hr. sa |
| 013 14H-TT | 85.52 | 106.90 | 128.28 | 143.00 | 213.97 | .16 | .20 | |
| 014 15H-TT | 85.52 | 106.90 | 128.28 | 71.00 | 213.97 | .08 | .20 | |
| 015 16H-1 | 17.28 | 21.60 | 25.92 | 22.00 | 36.00 | .12 | .20 | |
| 016 16H-2 | 7.20 | 9.00 | 10.80 | .10 | 27.02 | .14 | .30 | |
| 017 16H-3 | 115.28 | 144.10 | 172.92 | 120.18 | 144.21 | .10 | .20 | |
| 018 16F-1 | 119.76 | 149.70 | 179.64 | 199.03 | 599.22 | .16 | [illegible] | [illegible] |

## Sulfates

Water Quality Standard 75 mg/

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| U. S. Steel | | | | | | | | |
| GW-1 | 19.9 | 28.9 | 40.7 | 8,450 | 15,270 | 35 | 45 | |
| GW-2 | 10.9 | 16.4 | 23.0 | 4,240 | 7,670 | 31 | 40 | |
| GW-2A | 1.4 | 2.2 | 3.9 | 459 | 1,140 | 25 | 35 | |
| GW-3 | 2.7 | 3.8 | 4.5 | 1,140 | 1,613 | 36 | 43 | |
| GW-3A | 0.4 | 1.7 | 3.7 | 355 | 926 | 25 | 30 | |
| GW-4 | 0.5 | 0.7 | 0.9 | 146 | 225 | 25 | 30 | |
| GW-5 | 82.4 | 87.7 | 95.3 | 18,300 | 23,850 | 25 | 30 | |
| GW-6 | 23.4 | 29.5 | 39.4 | 8,610 | 14,940 | 35 | 45 | |
| GW-7 | 5.8 | 10.6 | 16.9 | 3,360 | 7,050 | 38 | 50 | |
| GW-7A | 93.3 | 120.1 | 146.0 | 35,350 | 54,700 | 35 | 45 | |
| GW-9 | 24.7 | 34.7 | 39.7 | 11,500 | 14,900 | 35 | 45 | |
| GW-10A | 26.3 | 34.6 | 47.2 | 8,660 | 15,730 | 30 | 40 | |
| GW-11A | 81.3 | 94.7 | 115.6 | 23,670 | 38,500 | 30 | 40 | |
| GW-13 | 1.8 | 2.9 | 4.8 | 1,450 | 4,000 | 60 | 100 | |
| ST-14 | 0.8 | 1.8 | 3.3 | 4,620 | 9,640 | 308 | 350 | |
| ST-17 | 20.1 | 30.0 | 39.3 | 48,750 | 75,300 | 195 | 230 | |
| GSTP | 44.0 | 52.7 | 62.0 | 28,600 | | 65 | | Grab sample |
| E.I. duPont | | | | | | | | |
| 001 | 0.5 | 1.8 | 2.4 | 7,670 | 25,200 | 511 | 1,258 | |
| 002-004 | 7.24 | 10.31 | 11.66 | 15,225 | 64,200 | 177 | 660 | |
| 005 | 0.07 | 0.08 | 0.12 | 300 | 2,700 | 450 | 2,693 | |
| 006-010 | 0.89 | 2.24 | 2.98 | 31,000 | 50,800 | 1,663 | 2,042 | |
| U.S.S. Lead | | 0.36 | | 665 | 2,740 | 221.4 | 912.5 | |
| HSTP | 35.0 | 40.7 | 44.0 | 40,700 | | 120 | | Grab sample |
| LCSTP | 10.0 | 14.0 | 20.0 | 11,100 | | 95 | | Grab sample |
| Union Carbide | 0.05 | 0.07 | 0.11 | 9 | 18 | 15 | 20 | |
| ARCO | | 5.04 | 6.77 | 16,800 | 28,200 | 400 | 500 | |
| Amer. St. Foundries | 0.09 | 0.15 | 0.27 | 48 | 113 | 38 | 50 | |

Continuous-Dry Weather Discharges (Continued)

Sulfates

Water Quality Standard 75

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comment |
|---|---|---|---|---|---|---|---|---|
| Youngstown | | | | | | | | |
| 001 YS-20 | 8.46 | 13.70 | 23.60 | 17,200 | 39,300 | 150 | 200 | |
| 002 YS-2 | 1.50 | 3.62 | 7.50 | 1,810 | 5,640 | 60 | 90 | |
| 003 YS-4 | 0.53 | 0.98 | 1.40 | 123 | 292 | 15 | 25 | |
| 004 YS-8 | 1.03 | 1.40 | 1.75 | 292 | 1,750 | 25 | 120 | |
| 005 YS-11 | 1.19 | 1.60 | 3.00 | 494 | 3,510 | 37 | 140 | |
| 006 YS-12 | 3.30 | 5.70 | 8.40 | 1,430 | 9,110 | 30 | 130 | |
| 007 YS-13 | 6.30 | 14.00 | 18.90 | 1,638 | 3,300 | 14 | 21 | |
| 008 YS-22 | 3.00 | 5.00 | 11.70 | 584 | 2,450 | 14 | 21 | |
| 009 YS-14 | 34.00 | 48.70 | 60.00 | 6,100 | 10,000 | 15 | 20 | |
| 010 YS-15 | 36.60 | 58.00 | 67.00 | 7,260 | 11,180 | 15 | 20 | |
| 011 YS-18A | 107.80 | 121.60 | 138.70 | 55,800<br>55,800 | 75,200<br>75,200 | 55<br>55 | 65<br>65 | |
| Inland | | | | | | | | |
| 001 IE-2 | | .14 | .29 | 88 | 180 | 75 | 90 | |
| 002 4E-1 | | 190.00 | 228.00 | 31,600 | 57,000 | 20 | 30 | |
| 003 5E-1 | | 7.20 | 8.60 | 1,800 | 3,590 | 30 | 50 | |
| 004 5E-2 | 8.60 | 0.86 | 1.04 | 165 | 261 | 23 | 30 | |
| 005 5E-3 | | 8.60 | 10.40 | 2,150 | 4,340 | 30 | 50 | |
| 006 6E-1 | | 0.65 | 1.30 | 136 | 433 | 25 | 40 | |
| 007 7E-1 | | 21.60 | 25.90 | 5,400 | 10,800 | 30 | 50 | |
| 008 10E-1 | Unknown & Highly Variable | | | | | | | |
| 011 13G-1 | 126.96 | 158.70 | 190.44 | 33,000 | 46,300 | 25 | 35 | |
| 012 13H-1 | 67.68 | 50.80 | 70.00 | 11,015.47 | 21,600.6 | 26 | 37 | |
| 013 14H-TT | 85.52 | 106.90 | 128.28 | 25,800 | 53,492.76 | 29 | 50 | |
| 014 15H-TT | 85.52 | 106.90 | 128.28 | 25,800 | 45,664.06 | 29 | 41 | |
| 015 16H-1 | 17.28 | 21.60 | 25.92 | 4,323.46 | 11,879.5 | 24 | 55 | |
| 016 16H-2 | 7.20 | 9.00 | 10.80 | 1,875 | 3,152.52 | 25 | 35 | |
| 017 16H-3 | 115.28 | 144.10 | 172.92 | 28,820 | 43,264.58 | 24 | 30 | |
| 018 16F-1 | 119.76 | 149.70 | 179.64 | 36,190 | 74,809.88 | 29 | 50 | |

# Inventory of Significant Continuous-Dry Weather Discharges

Phosphorus Water Quality Standard .1 mg/l

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| U. S. Steel | | | | | | | | |
| GW-1 | 19.9 | 28.9 | 40.7 | 17.00 | 23.78 | .05 | .07 | |
| GW-2 | 10.9 | 16.4 | 23.0 | 5.50 | 9.58 | .04 | .05 | |
| GW-2A | 1.4 | 2.2 | 3.9 | .74 | 1.60 | .04 | .05 | |
| GW-3 | 2.7 | 3.8 | 4.5 | .95 | 1.90 | .03 | .05 | |
| GW-3A | 0.4 | 1.7 | 3.7 | .57 | 1.50 | .04 | .05 | |
| GW-4 | 0.5 | 0.7 | 0.9 | .23 | .40 | .04 | .05 | |
| GW-5 | 82.4 | 87.7 | 95.3 | 65.80 | 87.40 | .09 | .11 | |
| GW-6 | 23.4 | 29.5 | 39.4 | 12.30 | 23.03 | .05 | .07 | |
| GW-7 | 5.8 | 10.6 | 16.9 | 8.84 | 21.15 | .10 | .15 | |
| GW-7A | 93.3 | 120.1 | 146.0 | 50.50 | 97.40 | .05 | .08 | |
| GW-9 | 24.7 | 34.7 | 39.7 | 8.69 | 13.24 | .03 | .04 | |
| GW-10A | 26.3 | 34.6 | 47.2 | 11.53 | 19.70 | .04 | .05 | |
| GW-11A | 81.3 | 94.7 | 115.6 | 31.60 | 48.40 | .04 | .05 | |
| GW-13 | 1.8 | 2.9 | 4.8 | 1.20 | 3.20 | .05 | .08 | |
| ST-14 | 0.8 | 1.8 | 3.3 | 3.05 | 7.42 | .20 | .27 | |
| ST-17 | 20.1 | 30.0 | 39.3 | 20.00 | 32.80 | .08 | .10 | |
| GSTP | 44.0 | 52.7 | 62.0 | 232.50 | 878.00 | .53 | 1.70 | |
| E.I. duPont | | | | | | | | |
| 001 | 0.5 | 1.8 | 2.4 | 7.00 | 35.00 | .56 | 1.75 | Net value |
| 002-004 | 7.24 | 10.31 | 11.66 | 13.00 | 25.00 | .15 | .26 | Net value |
| 005 | 0.07 | 0.08 | 0.12 | - | - | - | - | |
| 006-010 | 0.89 | 2.24 | 2.98 | - | - | - | - | |
| U.S.S. Lead | | 0.36 | | - | - | - | - | No net additio |
| HSTP | 35.0 | 40.7 | 44.0 | 115.30 | 550.00 | .34 | 1.50 | |
| ECSTP | 10.0 | 14.0 | 20.0 | 35.00 | 162.80 | .30 | .10 | |
| Union Carbide | 0.05 | 0.07 | 0.11 | .27 | | .46 | | |
| ARCO | | 5.04 | 6.77 | 180.80 | 486.00 | 4.30 | 8.60 | |
| Amer. St. Foundries | 0.09 | 0.15 | 0.27 | .13 | | .14 | | |

## Inventory of Significant Continuous-Dry Weather Discharges (Continued)

Phosphorus — Water Quality Standard .1

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| Youngstown | | | | | | | | |
| 001 YS-20 | 8.46 | 13.70 | 23.60 | 9.41 | | .08 | | Intake ave |
| 002 YS-2 | 1.50 | 3.62 | 7.50 | 2.49 | | .08 | | Intake a |
| 003 YS-4 | 0.53 | 0.98 | 1.40 | .98 | | .12 | | Intake ave |
| 004 YS-8 | 1.03 | 1.40 | 1.75 | .70 | | .06 | | Intake a |
| 005 YS-11 | 1.19 | 1.60 | 3.00 | 1.33 | | .10 | | Intake ave |
| 006 YS-12 | 3.30 | 5.70 | 8.40 | 3.33 | | .07 | | Intake av |
| 007 YS-13 | 6.30 | 14.00 | 18.90 | 9.62 | | .08 | | Intake av |
| 008 YS-22 | 3.00 | 5.00 | 11.70 | 4.17 | | .10 | | Intake av |
| 009 YS-14 | 34.00 | 48.70 | 60.00 | 24.37 | | .06 | | Intake ave |
| 010 YS-15 | 36.60 | 58.00 | 67.00 | 48.37 | | .10 | | Intake av |
| 011 YS-18A | 107.80 | 121.60 | 138.70 | 60.70 | | .06 | | Intake ave |
| Inland | | | | | | | | |
| 001 IE-2 | | .14 | .29 | 1.40 | | 1.20 | | |
| 002 4E-1 | | 190.00 | 228.00 | 63.38 | | .04 | | |
| 003 5E-1 | | 7.20 | 8.60 | 6.00 | | .10 | | |
| 004 5E-2 | 8.60 | 0.86 | 1.04 | .29 | | .04 | | |
| 005 5E-3 | | 8.60 | 10.40 | 4.30 | | .06 | | |
| 006 6E-1 | | 0.65 | 1.30 | .43 | | .08 | | |
| 007 7E-1 | | 21.60 | 25.90 | 5.40 | | .03 | | |
| 008 10E-1 | Unknown & Highly Variable | | | | | | | |
| 011 13G-1 | 126.96 | 158.70 | 190.44 | 26.00 | 79.41 | .02 | .05 | Maximum<br>24 hr. sample |
| 012 13H-1 | 67.68 | 50.80 | 70.00 | 12.71 | 35.03 | .03 | .06 | Maximum<br>24 hr. sample |
| 013 14H-TT | 85.52 | 106.90 | 128.28 | 9.00 | 32.09 | .01 | .03 | Maximum<br>24 hr. sample |
| 014 15H-TT | 85.52 | 106.90 | 128.28 | 9.00 | 32.09 | .01 | .03 | |
| 015 16H-1 | 17.28 | 21.60 | 25.92 | 9.00 | 32.42 | .05 | .15 | Maximum<br>24 hr. sample |
| 016 16H-2 | 7.20 | 9.00 | 10.80 | 8.00 | 27.02 | .11 | .30 | |
| 017 16H-3 | 115.28 | 144.10 | 172.92 | 12.00 | 43.26 | .01 | .03 | |
| 018 16F-1 | 119.76 | 149.70 | 179.64 | 37.00 | 62.00 | .03 | .05 | Maximum<br>24 hr. sample |

## BOD$_5$

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| U. S. Steel | | | | | | | | |
| GW-1 | 19.9 | 28.9 | 40.7 | 487.0 | 1,360.0 | 2 | 4 | |
| GW-2 | 10.9 | 16.4 | 23.0 | 410.0 | 4,800.0 | 3 | 25 | |
| GW-2A | 1.4 | 2.2 | 3.9 | 36.8 | 130.3 | 2 | 4 | |
| GW-3 | 2.7 | 3.8 | 4.5 | 95.0 | 525 | 3 | 14 | |
| GW-3A | 0.4 | 1.7 | 3.7 | 28.4 | 123.6 | 2 | 4 | |
| GW-4 | 0.5 | 0.7 | 0.9 | 11.7 | 30.1 | 2 | 4 | |
| GW-5 | 82.4 | 87.7 | 95.3 | 1,469.0 | 3,180.0 | 2 | 4 | |
| GW-6 | 23.4 | 29.5 | 39.4 | 493.0 | 1,317.0 | 2 | 4 | |
| GW-7 | 5.8 | 10.6 | 16.9 | 177.3 | 564.0 | 2 | 4 | |
| GW-7A | 93.3 | 120.1 | 146.0 | 3,003.0 | 6,100.0 | 3 | 5 | |
| GW-9 | 24.7 | 34.7 | 39.7 | 580.0 | 1,327.0 | 2 | 4 | |
| GW-10A | 26.3 | 34.6 | 47.2 | 578.0 | 1,583.0 | 2 | 4 | |
| GW-11A | 81.3 | 94.7 | 115.6 | 1,593.0 | 3,860.0 | 2 | 4 | |
| GW-13 | 1.8 | 2.9 | 4.8 | 48.5 | 161.0 | 2 | 4 | |
| ST-14 | 0.8 | 1.8 | 3.3 | 30.1 | 110.0 | 2 | 4 | |
| ST-17 | 20.1 | 30.0 | 39.3 | 3,000.0 | 7,220.0 | 12 | 22 | |
| GSTP | 44.0 | 52.7 | 62.0 | 12,100.0 | 36,700.0 | 27.6 | 71.0 | |
| E.I. duPont | | | | | | | | |
| 001 | 0.5 | 1.8 | 2.4 | 100.0 | 200.0 | 7 | 50 | |
| 002-004 | 7.24 | 10.31 | 11.66 | | | | | |
| 005 | 0.07 | 0.08 | 0.12 | | | - | - | No net additio |
| 006-010 | 0.89 | 2.24 | 2.98 | .7 | 2.0 | 1 | 2 | |
| | | | | | | 1 | 2 | |
| U.S.S. Lead | | 0.36 | | 5.2 | | 2 | 4 | |
| HSTP | 35.0 | 40.7 | 44.0 | 7,800.0 | 36,780.0 | 23 | 100 | |
| ECSTP | 10.0 | 14.0 | 20.0 | 6,900.0 | 18,200.0 | 59 | 109 | |
| Union Carbide | 0.05 | 0.07 | 0.11 | 1 | 2 | 1 | 3 | |
| ARCO | | 5.04 | 6.77 | 400.0 | | 10.5 | 28.6 | |
| Amer. St. Foundries | 0.09 | 0.15 | 0.27 | 1 | 3 | 1 | 2 | |

## Inventory of Significant Continuous-Dry Weather Discharges (Continued)

### BOD$_5$

| Discharges | Min. Flow (MGD) | Avg. Flow (MGD) | Max. Flow (MGD) | Avg. Load (lb/day) | Max. Load (lb/day) | Avg. Conc. (mg/l) | Max. Conc. (mg/l) | Comments |
|---|---|---|---|---|---|---|---|---|
| Youngstown | | | | | | | | |
| 001 YS-20 | 8.46 | 13.70 | 23.60 | 566.0 | 855.0 | 6.0 | 8.0 | |
| 002 YS-2 | 1.50 | 3.62 | 7.50 | 45.3 | 67.9 | 1.5 | 2.25 | |
| 003 YS-4 | 0.53 | 0.98 | 1.40 | 14.7 | 22.1 | 1.8 | 2.7 | |
| 004 YS-8 | 1.03 | 1.40 | 1.75 | 63.1 | 94.6 | 5.4 | 8.1 | |
| 005 YS-11 | 1.19 | 1.60 | 3..00 | 34.7 | 52.0 | 2.6 | 3.9 | |
| 006 YS-12 | 3.30 | 5.70 | 8.40 | 489.2 | 734.0 | 10.4 | 15.6 | Not meanir due to cya conc. |
| 007 YS-13 | 6.30 | 14.00 | 18.90 | 362.5 | 549.6 | 3.1 | 4.7 | |
| 008 YS-22 | 3.00 | 5.00 | 11.70 | 1,158.0 | 1,737.0 | 27.8 | 41.7 | |
| 009 YS-14 | 34.00 | 48.70 | 60.00 | 3,183.0 | 2,503.0 | 3.4 | 5.0 | |
| 010 YS-15 | 36.60 | 58.00 | 67.00 | 1,695.0 | 2,796.0 | 3.5 | 5.0 | |
| 011 YS-18A | 107.80 | 121.60 | 138.70 | 1,622.0 | 2,433.0 | 1.6 | 2.4 | |
| Inland | | | | | | | | |
| 001 1E-2 | | .14 | .29 | 2.3 | 9.7 | 3.0 | 4.0 | |
| 002 4E-1 | | 190.00 | 228.00 | 3,174.0 | 7,620.0 | 2.0 | 4.0 | |
| 003 5E-1 | | 7.20 | 8.60 | 120.0 | 288.0 | 2.0 | 4.0 | |
| 004 5E-2 | 8.60 | 0.86 | 1.04 | 14.3 | 34.8 | 2.0 | 4.0 | |
| 005 5E-3 | | 8.60 | 10.40 | 143.0 | 348.0 | 14.0 | 18.0 | |
| 006 6E-1 | | 0.65 | 1.30 | 27.1 | 86.6 | 5.0 | 8.0 | |
| 007 7E-1 | | 21.60 | 25.90 | 361.0 | 865.0 | 2.0 | 4.0 | |
| 008 10E-1 | Unknown & Highly Variable | | | | | 2.0 | 4.0 | |
| 011 13G-1 | 126.96 | 158.70 | 190.44 | 2,640.0 | 2,640.0 | 2.0 | 2.0 | |
| 012 13H-1 | 67.68 | 50.80 | 70.00 | 847.34 | 1,751.4 | 2.0 | 3.0 | |
| 013 14H-TT | 85.52 | 106.90 | 128.28 | 6,240.82 | 16047.83 | 7.0 | 15.0 | |
| 014 15H-TT | 85.52 | 106.90 | 128.28 | 6,240.82 | 18187.54 | 7.0 | 17.0 | |
| 015 15H-1 | 17.28 | 21.60 | 25.92 | 360.0 | 540.43 | 2.0 | 2.5 | |
| 016 16H-2 | 7.20 | 9.00 | 10.80 | 150.0 | 225.0 | 2.0 | 3.0 | |
| 017 16H-3 | 115.28 | 144.10 | 172.92 | 4,800.0 | 6,000.0 | 4.0 | 5.0 | |
| 018 16F-1 | 119.76 | 149.70 | 179.64 | 2,500.0 | 3,740.0 | 2.0 | 3.0 | |

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APPENDIX B

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# MULTIGOAL WATER QUALITY PLANNING MODEL

By David E. Pingry[1] and Andrew B. Whinston[2]

## INTRODUCTION

The recent public interest in the water quality problem has led to the construction of river basin simulation models which are used to determine the water quality effects of given effluent patterns. These models have been used to form the constraints for mathematical programming problems of the form—Minimize: Treatment Costs, Subject to: Quality Goals Satisfied. Using these models a considerable case has been made for treating water pollution as a regional or basin wide problem, instead of imposing discharge limitations and deciding on the construction of treatment plants on an *ad hoc* basis. Examples of the water quality models can be found in Graves, et al. (5,6), Loucks, et al. (9), Schaumburg (13), and Revelle, et al. (12). The reason for this approach is that the effect on water quality of waste discharge in a particular river varies greatly with the actual point of discharge. On the other hand, in an area with a large concentration of water users, the addition of further treatment, flow augmentation, or other means of treatment can have a significant effect on improving water quality. Thus, for any given set of quality goals for a river, significantly different policies for each polluter may be appropriate. This can be contrasted with current regulations that impose various uniform rules such as secondary treatment regardless of the effect on the quality goals. Once a regional approach is being considered other treatment strategies may also be evaluated alongside treatment at polluters. Combining effluent from various sources and treating it in a large regional plant may, because of possible economies of scale, lead to a lower

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per unit cost. Low flow augmentation, by-pass piping, and in-stream aeration are other possibilities that, if used judiciously, can achieve further economies.

While it is understood that in view of the large variation in stream assimilative capacity, uniform rules introduce significant inefficiencies, the problems of organizing and implementing a scheme that takes advantage of the difference may be extremely difficult. In order to effectively determine the most economical way of achieving the water quality standards basin wide, enormous amounts of information must be available in a form that can be analyzed to make these decisions. This problem is twofold:

1. Collection and organization of data to determine water quality (and implicitly water use) implied by alternative treatment strategies.
2. Isolation of efficient solutions, i.e., the least cost combinations of treatment strategies given the water quality (water use) goals.

The planning model presented in this paper attacks both of these problems. A simulation model of the river basin water quality serves as the constraint set for an optimization model that searches for the efficient solutions given the quality goals.

The major contributions of the basin planning model presented in this paper are: (1) The explicit consideration of the interaction of temperature and the dissolved oxygen levels; and (2) the simultaneous considerations of several alternative treatment strategies.

This paper will present an integration of the traditional Streeter and Phelps dissolved oxygen model with a heat decay model. The resulting quality model will be incorporated in a nonlinear programming river basin model that includes the treatment alternatives of regional plants, by-pass piping, low-flow augmentation, and cooling towers.

## DISSOLVED OXYGEN—TEMPERATURE MODEL

A model of the relationship between dissolved oxygen levels (DO) atmospheric reaeration, and bacterial respiration was formulated by Streeter and Phelps in 1925 (14). The relations were expanded by the addition of further sources and sinks by O'Conner (11), Dobbins (1), and others.

The model presented by Streeter and Phelps can be described as follows. Assume

$$\frac{dB}{dt} = -K_1 B \quad (1)$$

and $$\frac{dD}{dt} = K_1 B - K_2 D \quad (2)$$

Eqs. 1 and 2 integrate to yield

$$B = B^0 C_1 \quad (3)$$

and $$D = KB^0(C_1 - C_2) + D^0 C_2 \quad (4)$$

$$C_1 = \exp(-K_1 t) \quad (5)$$

$$C_2 = \exp(-K_2 t) \quad (6)$$

$$K = \frac{K_1}{K_2 - K_1} \quad (7)$$

For the purpose of this paper an empirical relationship between the flow velocity and the volumetric flow is assumed to have the form:

$$v = \delta F^{\sigma} \quad (8)$$

in which δ and σ are parameters estimated for each river segment.

It is also assumed that the rate of reaeration depends on the velocity of flow and therefore, the volumetric flow rate. This relationship is assumed to have the form

$$K_2^{20} = \phi F^{\mu} \quad (9)$$

in which ϕ and μ are estimated parameters determined at 20° C.

The behavior of temperature in rivers has been described by Dysart and Hines (2) and Jaworski, et al. (7), using an exponential decay model similar to the one presented previously for biochemical oxygen demand (BOD). Assume:

$$\frac{d(T - T_E)}{dt} = -K_3(T - T_E) \quad (10)$$

Eq. 10 integrates to yield

$$T - T_E = (T^0 - T_E) C_3 \quad (11)$$

in which $$C_3 = \exp(-K_3 t) \quad (12)$$

As was noted in the previous section, the temperature affects the rate of the deoxygenation and reaeration reactions. These relations have been assumed to have the form

$$K_1 = K_1^{20} \theta_1^{T-20} \quad (13)$$

$$K_2 = K_2^{20} \theta_2^{T-20} \quad (14)$$

in which $K_1^{20}$ and $K_2^{20}$ are the experimentally determined values of $K_1$ and $K_2$ at 20° C; and $\theta_1$ and $\theta_2$ are estimated parameters. Also, the level of saturation of dissolved oxygen in water is affected by the temperature. This directly affects the level of the dissolved oxygen deficit or DOD. The relation between temperature and the dissolved oxygen saturation level is usually assumed to be

$$D_s = \sum_{i=1}^{4} \delta_i T^{i-1} \quad (15)$$

in which the $\delta_i$ values are estimated parameters. Applications of Eqs. 13-15 can be found in Refs. 2, 7 and 15. Eqs. 13-15 can easily be substituted into Eqs. 3 and 4 to determine dissolved oxygen sag curves for each different level of temperature.

The procedure described previously to relate temperature and dissolved oxygen is correct as long as the basin temperature is fixed. However, if some of the [illegible] of [illegible] temperature [illegible] above [illegible] values given the meteorological conditions) then a model as in Eq. 10 is appropriate for the temperature. This implies a three equation differential equation model including Eqs. 1, 2, and 10 should be solved to predict the level of dissolved oxygen. This was noted by Dysart and Hines (1). However, they did not solve the new systems of equations, but used the temperature decay model to fix the temperature at a point and assume that level constant over a small river section. In this paper, we solve the three equation system and apply the solution to a river basin model. This allows the addition of thermal quality constraints to the basin model, and consideration of cooling tower as a waste treatment system not only for heat pollution, but also for increasing dissolved oxygen.

The new model which will include the decay of temperature can be written:

$$\frac{d(T-T_E)}{dt} = -K_3(T-T_E) \qquad (16)$$

$$\frac{dB}{dt} = -K_1 B \qquad (17)$$

$$\frac{dD}{dt} = K_1 B - K_2 D \qquad (18)$$

$$K_1 = K_1^{20}\theta_1^{T-20} \qquad (19)$$

$$K_2 = \phi F^{\mu}\theta_2^{T-20} \qquad (20)$$

$$D_S = \sum a_i T^{i} \qquad (21)$$

For the purpose of solving this system, it is useful to note the causality relations assumed. Temperature affects the dissolved oxygen level both directly and through biological oxygen demand. The biological oxygen demand affects the dissolved oxygen deficit directly. These relations imply that we can solve Eq. 16 independently and substitute the solution into Eqs. 17 and 18. Eq. 17 can then be solved and substituted into Eq. 18 which can then be solved to complete the solution of the system.

Proceeding in the manner prescribed, we note that the solution to Eq. 16 is the same as the one presented in Eq. 11:

$$T = T_E + (T^o - T_E)C_3 \qquad (22)$$

The value for $T$ can be substituted into Eq. 17 to yield

$$\frac{dB}{dt} = (-A_1\theta_1^{\bar{T}C_3})B \qquad (23)$$

in which $A_1 = K_1^{20}\theta_1^{T_E-20}$ (24)

$$\bar{T} = T^o - T_E \qquad (25)$$

The solution to Eq. 17 is obtained by rewriting Eq. 23 in the form

$$\frac{dB}{B} = (-A_1\theta_1^{\bar{T}C_3})dt \qquad (26)$$

and integrating both sides. The integration of the right-hand side of Eq. 26 is found by approximating the function with Maclaurin series expansion and integrating each term. The solution to Eq. 17 is

$$B = B^o\exp\left(-\beta_o K_3 t + \sum_{n=1}^{\bar{n}}\beta_n C_3^n - \sum_{n=1}^{\bar{n}}\beta_n\right) \qquad (27)$$

in which $\beta_o = \dfrac{A_1}{K_3}$ (28)

and $\beta_n = \dfrac{\beta_o(\ln\theta_1)^n\bar{T}^n}{n!\,n}$; $n = 1, \bar{n}$ (29)

The value of $\bar{n}$ depends on the number of members of the infinite series necessary to achieve the desired accuracy.

Note that if the temperature is assumed to be fixed at the equilibrium value then Eq. 27 reduces to

$$B = B^o\exp(-A_1 t) \qquad (30)$$

which is the solution to the original Streeter and Phelps equations with temperature treated as a parameter in the system.

Given the solutions to Eqs. 16 and 17 the solution to Eq. 18 can now be obtained. The solutions to Eqs. 16 and 17 are substituted into Eq. 18 to obtain

$$dD = A_1\theta_1^{\bar{T}C_3}B^o\exp\left(-\beta_o K_3 t + \sum_{n=1}^{\bar{n}}\beta_n C_3^n - \sum_{n=1}^{\bar{n}}\beta_n\right) - (A_2\theta_2^{\bar{T}C_3})D \qquad (31)$$

in which $A_2 = \phi F\mu\,\theta_2^{T_E-20}$ (32)

If we rewrite Eq. 31 in the form

$$\frac{dD}{dt} + P(t)D = Q(t) \qquad (33)$$

in which $P(t) = A_2\theta_2^{\bar{T}C_3}$ (34)

$$Q(t) = A_1\theta_1^{\bar{T}C_3}B^o\exp\left(-\beta_o K_3 t + \sum_{n=1}^{\bar{n}}\beta_n C_3^n - \sum_{n=1}^{\bar{n}}\beta_n\right) \qquad (35)$$

we see that it is a linear first-order differential equation which can be solved by multiplying both sides by $u(t)$, in which

$$u(t) = \exp\left[\int P(t)dt\right] \qquad (36)$$

The left-hand side is then the exact differential of $D\exp\left[\int P(t)dt\right]$ and the right-hand side is a function of $t$ only. Both sides can now be integrated to obtain the solution to Eq. 18.

The first step is to evaluate $u(t)$. The function, $u(t)$, can be written as

$$u(t) = \exp\left[\int A_2\theta_2^{\bar{T}C_3}dt\right] \qquad (37)$$

The integral in the exponent is of the same form as the right-hand side of Eq. 26. Using the solution to Eq. 26 we can obtain the solution to this integral which is

$$\lambda_o(\ln T - K_1 t) + \sum_{n=1}^{n} \lambda_n C_1^n \quad \text{(38)}$$

in which $\lambda_o = \dfrac{\lambda_2}{K_1}$ (39)

and $\lambda_n = \dfrac{\lambda_o(\ln\theta_2)^n T^n}{n!\,n}$; $n = 1, n$ (40)

The solution to the left-hand side of Eq. 33 is

$$\left[\int P(t)\,dt\right] = D\exp\left[\lambda_o(\ln T - K_1 t) + \sum_{n=1}^{n} \lambda_n C_1^n\right] \quad \text{(41)}$$

The right-hand side of Eq. 33 is now a function of $t$ only, and the integral with respect to $t$ can be written as

$$\int u(t)\,Q(t)\,dt = \int B^n \alpha \exp\left(\alpha_o t + \sum_{n=1}^{n} \alpha_n C_1^n\right) dt \quad \text{(42)}$$

in which $\alpha = A_1 \exp\left(\lambda_o \ln T - \sum_{n=1}^{n} \beta_n\right)$ (43)

$$\alpha_o = K_1(\lambda_o + \beta_o) \quad \text{(44)}$$

$$\alpha_n = \lambda_n + \beta_n \quad \text{(45)}$$

Again, we use the Maclaurin series approximation technique. If we let

$$f(t) = u(t)\,Q(t) \quad \text{(46)}$$

the integral, Eq. 42 can be written

$$\int f(t)\,dt = f(0)t + \sum_{m=1}^{m} \frac{f^m(0)\,t^{m+1}}{(m+1)!} \quad \text{(47)}$$

In order to evaluate Eq. 47 explicitly let

$$f(t) = B^n \alpha \exp[\alpha_o t + y(t)] \quad \text{(48)}$$

in which $y(t) = \sum_{n=1}^{n} \alpha_n C_1^n$ (49)

The derivatives of $f(t)$ are

$$\left.\begin{aligned} f^1(t) &= \rho f(t) \\ f^2(t) &= \rho f^1(t) + y^2(t)\,f(t) \\ f^3(t) &= \rho f^2(t) + 2\,y^2(t)\,f^1(t) + y^3(t)\,f(t) \\ f^4(t) &= \rho f^3(t) + 3\,y^2(t) + 3\,y^3(t)\,f^1(t) + y^4(t)\,f(t) \end{aligned}\right\} \quad \text{(50)}$$

or, in general

$$f^k(t) = \rho f^{k-1}(t) + \sum_{i=1}^{k-1} \frac{(k-1)!}{i!\,(k-1-i)!}\, y^{i+1}(t)\, f^{k-1-i}(t); \quad k \geq 2$$

in which $\rho = \alpha_o + y^1(t)$ (51)

The derivatives of $y(t)$ are

$$\left.\begin{aligned} y^1(t) &= \sum_{n=1}^{n} \alpha_n(-nk_1)\,C_1^n \\ y^2(t) &= \sum_{n=1}^{n} \alpha_n(-nk_1)^2\,C_1^n \\ \text{or, in general}\quad y^j(t) &= \sum_{n=1}^{n} \alpha_n(-nK_1)^j\,C_1^n \end{aligned}\right\} \quad \text{(52)}$$

When $t = 0$ the derivatives of $y(t)$ are

$$\left.\begin{aligned} y^1(0) &= \sum_{n=1}^{n} \alpha_n(-nK_3) \\ y^2(0) &= \sum_{n=1}^{n} \alpha_n(-nK_3)^2 \\ \text{or, in general}\quad y^j(0) &= \sum_{n=1}^{n} \alpha_n(-nK_3)^j \end{aligned}\right\} \quad \text{(53)}$$

Using this information the values of $f(0)$, $f^1(0)$, …, $f^n(0)$ can be determined:

$$\left.\begin{aligned} f(0) &= B^n \alpha \exp\left(\sum_{n=1}^{n} \alpha_n\right) \\ f^1(0) &= \left[\alpha_o + \sum_{n=1}^{n}(-nK_3\alpha_n)\right] f(0) \\ f^2(0) &= \left[\alpha_o + \sum_{n=1}^{n}(-nK_3)\alpha_n\right] f^1(0) + \left[\sum_{n=1}^{n}(-nK_3)^2\alpha_n\right] \\ &\text{or, in general} \\ f^k(0) &= \left[\alpha_o + \sum_{n=1}^{n}(-nK_3)\alpha_n\right] f^{k-1}(0) \\ &+ \sum_{i=1}^{k-1} \frac{(k-1)!}{i!\,(k-1-i)!}\left[\sum_{n=1}^{n}(-nK_3)^{i+1}\alpha_n\right] f^{k-1-i}(0) \end{aligned}\right\} \quad \text{(54)}$$

The integral of the right-hand side of Eq. 33 can now be expressed explicitly in terms of the previous expressions.

Combining the solutions to the right and left-hand sides of Eq. 33 yield the

$$D = \exp\left[\lambda_a(\ln T - K_1 t) + \sum_{n=1}^{n} \lambda_n C_1^n\right]\left[f(0)t + \sum_{m=1}^{m} \frac{f^m(0)t^{m+1}}{(m+1)!} + C\right] \quad (55)$$

The constant of integration is

$$C = D' \exp\left(\lambda_a \ln T + \sum_{n=1}^{n} \lambda_n\right) \quad (56)$$

The solution to the original Streeter-Phelps equation can be determined by adding and subtracting the constant, $B_a/\alpha_a$, from the right-hand side and noting that the terms left, excluding the constant, $C$, are a Maclaurin series expansion for $(1/\alpha_a)C^{n+1}$.

Eqs. 22, 27, and 55 can be rewritten as

$$T = T_E + (T'' - T_E) C_1 \quad (57)$$

$$B = B'' C_4 \quad (58)$$

$$D = C_5^{-1}\left[f(0)t + \sum_{m=1}^{n} \frac{f^m(0)t^{m+1}}{(m+1)!} + D'' C_6\right] \quad (59)$$

in which $C_4 = \exp\left(-\beta_a K_1 t - \sum_{n=1}^{n} \beta_n C_1^n - \sum_{n=1}^{n} \beta_n C_2^n - \sum_{n=1}^{n} \beta_n\right)$ (60)

$$C_5 = \exp\left[\lambda_a(\ln T - K_1 t) + \sum \lambda_n C_1^n\right] \quad (61)$$

$$C_6 = \exp\left(\lambda_a \ln T - \sum_{n=1}^{n} \lambda_n\right) \quad (62)$$

The implicit form of the solution to this model is

$$T = T(F, T'' \mid T_E, K_1, \alpha, \delta, \sigma) \quad (63)$$

$$B = B(F, T'', B'' \mid T_E, K_3, \alpha, \delta, \sigma, \theta_1 K_1^{2n}) \quad (64)$$

$$D = D(F, T'', B'', D'' \mid T_E, K_1, \alpha, \delta, \sigma, \theta_1, K_1^{2n}, \theta_2, \mu, \phi) \quad (65)$$

## NONLINEAR PROGRAMMING RIVER BASIN PLANNING MODEL

Using the water quality relationships described in the previous section, a programming model of the following form can be constructed—Minimize: Total cost of abatement structures. Subject to: Water quality goals satisfied.

The constraints of this model are constructed by dividing the river into sections and constraining the water quality to be met at the end of each section. A new section begins where one of the following occurs: (1) Effluent flow enters the river; (2) incremental flow enters the river (ground water, tributary flow, etc.); (3) the flow in the main channel is augmented or diverted; and (4) "state" parameters are altered.

Although new sections must be introduced where one of the aforementioned occurs, another important consideration is the length of the section which should not be so long that it would allow the dissolved oxygen sag curve to be completely contained in its length. This may require additional unnecessary sections for entering flows or parameter changes. The river sections are numbered sequentially, starting with the headwaters section including possible tributaries of a maximum length of one section (see Fig. 1). The values of $F$, $T''$, $B''$ and $D''$ must be recalculated at the headwaters of each section, and are a function of the various quality control strategies employed. The cost of the basin system or objective function of the nonlinear model is also dependent on the alternative control strategies.

For this model we will assume the following alternative control strategies: (1) By-pass piping; (2) flow augmentation; (3) regional and on-site treatment plants, and (4) cooling towers. The control variables associated with these strategies are: $f_{gi}$ = flow from polluter $i$ to section $g$; $p_{mi}$ = flow from polluter i to treatment plant $m$; $t_{gm}$ = flow from treatment plant $m$ to section $g$; $r_m$ = percentage removal of BOD at treatment plant $m$; $F_{g1}$ = augmentation flow in section g; and $s_g$ = percentage removal of heat in cooling tower in section g. The particular pattern of piping flows determines the regional and on-site plants operating.

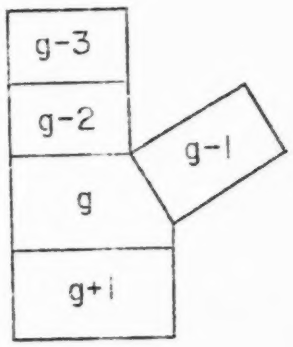

FIG. 1.—Typical Sections

There is an implicit assumption that the two groups of polluters are mutually exclusive, i.e., heat polluters are not BOD polluters and vice versa. Operationally, the assumption is that the temperature of all BOD flow is $T_E$, and the BOD and DOD of the heat effluent are assumed to have some constant value. The cooling alternative consists of simply building an on-site cooling tower or dumping directly. This limiting assumption does not appear to be serious since the major thermal polluters are power plants that do not directly affect BOD levels to a great degree. The major problem caused by the removal of this assumption would be the modeling of the cooling that would take place in a BOD treatment plant and the BOD oxidation that would take place in a cooling tower.

In order to determine the explicit nonlinear programming planning model one must express the values of $F$, $T''$, $B''$, and $D''$ at the head of each river section as functions of the control variables. These relations are conditional depending on the location of the particular section relative to the tributaries.

If $g$ is the headwaters section or a tributary

$$F_g = \sum_{i=1}^{I} F_{gi} \quad \ldots \ldots (66)$$

$$T_g^a = \sum_{i=1}^{I} T_{gi}\frac{F_{gi}}{F_g} \quad \ldots \ldots (67)$$

$$B_g^a = \sum_{i=1}^{I} B_{gi}\frac{F_{gi}}{F_g} \quad \ldots \ldots (68)$$

$$D_g^a = \sum_{i=1}^{I} D_{gi}\frac{F_{gi}}{F_g} \quad \ldots \ldots (69)$$

If section g is neither a tributary nor directly preceeded by a tributary

$$F_g = \sum_{i=1}^{I} F_{gi} + F_{g-1} \quad \ldots \ldots (70)$$

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$$T_g^a = \frac{\sum_{i=1}^{I} T_{gi}F_{gi} + T_{g-1}F_{g-1}}{F_g} \quad \ldots \ldots (71)$$

$$B_g^a = \frac{\sum_{i=1}^{I} B_{gi}F_{gi} + B_{g-1}F_{g-1}}{F_g} \quad \ldots \ldots (72)$$

$$D_g^a = \frac{\sum_{i=1}^{I} D_{gi}F_{gi} + D_{g-1}F_{g-1}}{F_g} \quad \ldots \ldots (73)$$

If section g is directly preceeded by a tributary

$$F_g = \sum_{i=1}^{I} F_{gi} + F_{g-1} + F_{g-2} \quad \ldots \ldots (74)$$

$$T_g^a = \frac{\sum_{i=1}^{I} T_{gi}F_{gi} + T_{g-1}F_{g-1} + T_{g-2}F_{g-2}}{F_g} \quad \ldots \ldots (75)$$

$$B_g^a = \frac{\sum_{i=1}^{I} B_{gi}F_{gi} + B_{g-1}F_{g-1} + B_{g-2}F_{g-2}}{F_g} \quad \ldots \ldots (76)$$

$$D_g^a = \frac{\sum_{i=1}^{I} D_{gi}F_{gi} + D_{g-1}F_{g-1} + D_{g-2}F_{g-2}}{F_g} \quad \ldots \ldots (77)$$

in which $F_{g2} = \sum_i f_{gi} + \sum_m t_{gm}$ ...... (78)

$$F_{g2}B_{g2} = \sum_i B_i f_{gi} + \sum_m (1 - r_m)\frac{\sum_i B_i p_{mi}}{\sum_i p_{mi}}\, t_{gm} \quad \ldots \ldots (79)$$

$$F_{g2}D_{g2} = \sum_i D_i f_{gi} + \sum_m \left(\frac{\sum_i D_i p_{mi}}{\sum_i p_{mi}}\, t_{gm}\right) \quad \ldots \ldots (80)$$

and $T_{g2} = (1 - s_g)(T_g^* - T_I) + T_I$ ...... (81)

The planning model can now be explicitly written in terms of the control variables as follows. Minimize:

$$TC = C^L + C^R + C^P + C^T \quad \ldots \ldots (82)$$

in which $C^L = \sum_g\sum_i C^L_{gi} + \sum_m\sum_i C^L_{mi} + \sum_g\sum_m C^L_{gm}$ ...... (83)

$$C^L_{gi} = 1.865\, a_{gi}\,(f_{gi})\,0.598 \quad \ldots \ldots (84)$$

$$C^L_{mi} = 1.865\, a_{mi}\,(p_{mi})\,0.598 \quad \ldots \ldots (85)$$

$$C^L_{gm} = 1.865\, a_{gm}\,(t_{gm})\,0.598 \quad \ldots \ldots (86)$$

$$C^R = \sum_g C^R_g F_{g3} \quad \ldots \ldots (87)$$

$$C^P = \sum_m 49.22\left(\sum_i p_{mi}\right)\frac{3}{4}\,[8.0\,(r_m - 0.5)^3 + 1] \quad \ldots \ldots (88)$$

$$C^T = \sum_g C^T_g s_g (T_g^* - T_I)\, F_{gi} \quad \ldots \ldots (89)$$

Subject to

$$T_g = T_g(F_g, T_g^a \mid T_{Eg}, a_g, \delta_g, \sigma_g) \leq \bar{T}_g \quad \ldots \ldots (90)$$

$$B_g = B_g(F_g, T_g^a, B_g^a \mid T_{Eg}, K_{1g}, a_g, \delta_g, \sigma_g, \theta_{1g}, K^{20}_{1g}) \leq \bar{B}_g, \text{ for all } g \quad \ldots \ldots (91)$$

$$D_g = D_g(F_g, T_g^a, B_g^a, D_g^a \mid T_{Eg}, K_{3g}, a_g, \delta_g, \sigma_g, \theta_{1g}, K^{20}_{1g}, \theta_{2g},$$
$$\mu_g, \phi_g) \leq \bar{D}_g \quad \ldots \ldots (92)$$

in which $f_g$, $T_g^a$, $B_g^a$, and $D_g^a$ are described as functions of the control variables in Eqs. 66-81. The following flow balance equations are also needed

$$\sum_g f_{gi} + \sum p_{mi} - \bar{f}_i = 0 \quad \ldots \ldots (93)$$

$$\sum_i p_{mi} - \sum_g t_{gm} = 0, \text{ for all } m \quad \ldots \ldots (94)$$

This explicitly states the planning model in terms of the control variables available to the planner.

The cost functions in this paper represent the annual cost of the capital and operation and maintenance of the appropriate structures. The cost functions for the treatment plants were obtained from Frankel (2). The cost functions for the piping from Linaweaver and Clark (7). The flow augmentation dam costs were obtained from the Evansville office of the Environmental Protection Agency for existing and proposed sites in the West Fork White Basin. For the purpose of this paper it was assumed that the expected flow from the reservoir was the upper bound and any flow augmentations less than this bound cost a proportional amount of the dam expenses. The cooling tower costs were also assumed to be proportional to the flow and number of degrees cooled.

It is recognized by the writers that many of the assumptions about the cost functions are debatable. The study of cost function generating techniques appropriate for such planning models is a very important area of research since the usefulness of these models depends critically on these functions. This problem is examined in detail in a recent paper by Marsden, Pingry, and Whinston (10).

The nature of this model is that the constraints are sequentially dependent on the concentrations of all the upstream flows. The temperature level affects the BOD and DOD levels directly and DOD levels indirectly through the BOD. The BOD level affects the DOD level directly. Since the level of BOD only affects the water quality indirectly through the DOD, the constraint set

$$B_g = B_g(F_g, F_g^c, B_g^0 \mid T_{1g}, K_{1g}, a_g, b_g, u_g, \theta_{1g}, K_{1g}^{2h}) \leq \bar{B}_g \quad \text{for all } g \quad . \quad . \quad (95)$$

can be eliminated from direct consideration. The BOD levels must still be calculated in order to determine the DOD levels. However, the constraints on DOD implicitly constrain the BOD levels.

## Summary and Conclusions

The river basin model presented in the paper facilitates the examination of a large number of water quality goals and associated costs.

## Acknowledgments

The development of the river simulation model in this paper owes much to the DOCAL computer program of the Environmental Protection Agency. This Program was originally developed by J. L. Worley of the Environmental Protection Agency and was applied on the West Fork White River by the Evansville office of the Environmental Protection Agency. We are especially grateful to Max Noecker and Stanley Smith of the Evansville office who kindly made their data and experience available for our use. The research was supported by the Army Research Office. The writers are indebted to the referees for their very helpful comments.

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## ENDIX II.—Notation

*he following symbols are used in this paper:*

$a_g$ = length of river section $g$;
$a_{gi}$ = length of pipe from polluter $i$ to river section $g$;
$a_{gm}$ = length of pipe from treatment plant $m$ to river section $g$;
$a_{mi}$ = length of pipe from polluter $i$ to treatment plant $m$;
, $B^o$ = biochemical oxygen demand (BOD) at time $t$ and $t = 0$;
$B_g$ = BOD goal in section $g$;
, $B_g^o$ = BOD at end and headwaters of section $g$;
$B_{g1}$ = BOD of incremental flow entering section $g$;
$B_{g2}$ = BOD of effluent flow entering section $g$;
$B_{g3}$ = BOD of augmentation flow entering section $g$;
$B_{g4}$ = BOD of thermal effluent flow entering section $g$;
$\bar{B}_i$ = BOD of effluent from polluter $i$;

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$D, D^0$ = dissolved oxygen deficit (DOD) at time $t$ and $t = 0$;
$D^e, D^h$ = DOD at end and headwaters of section $g$;
[illegible] = DOD goal in section $g$;
$D_{gi}$ = DOD of incremental flow entering section $g$;
$D_{ge}$ = DOD of effluent flow entering section $g$;
$D_{ga}$ = DOD of augmentation flow entering section $g$;
$D_{gt}$ = DOD of thermal effluent flow entering section $g$;
$D_i$ = DOD of effluent from polluter $i$;
$D_s$ = dissolved oxygen saturation level;
$F$ = river flow;
$F_g$ = river flow in section $g$;
$F_{gi}$ = incremental flow entering section $g$;
$F_{ge}$ = effluent flow entering section $g$;
$F_{ga}$ = augmentation flow entering section $g$;
$F_{gt}$ = thermal effluent flow entering section $g$;
$f_{ig}$ = flow from polluter $i$ to section $g$;
$f_i$ = effluent flow from polluter $i$;
$K_1$ = deoxygenation rate parameter;
$K_1^{20}$ = deoxygenation rate parameter at 20° C;
$K_2$ = reaeration rate parameter;
$K_2^{20}$ = reaeration rate parameter at 20° C;
$K$ = heat decay parameter;
$p_{im}$ = flow from polluter $i$ to treatment plant $m$;
$r_m$ = percent removal BOD at treatment plant $m$;
$s_g$ = percentage removal of thermal effluent at cooling tower $g$;
$T, T^0$ = temperature at time $t$ and $t = 0$;
$\bar{T}$ = temperature goal in section $g$;
$T_E$ = equilibrium basin temperature;
$T^*$ = temperature of thermal effluent at section $g$;
$T^e, T^h$ = temperature at end and headwaters of section $g$;
$t$ = time;
$t_{gm}$ = flow from treatment plant into river section $g$;
$v$ = velocity of river flow;
$v_g$ = velocity of river flow in section $g$;
$\epsilon, \epsilon_g$ = estimated parameter in Eq. [illegible]
$\delta_g$ = estimated parameters in Eq. 15;
$\theta_{1g}$ = estimated parameters in Eq. 13;
$\theta_{2g}$ = estimated parameters in Eq. 14;
$\mu, \mu_g$ = estimated parameters in Eq. 9;
$\alpha, \alpha_g$ = estimated parameters in Eq. 8; and
$\phi, \phi_g$ = estimated parameters in relation (9).

# APPENDIX C

## LITERATURE REVIEW

The 1972 FWPCAA specified that water quality goals be achieved according to the following schedule:

- By midyear 1977, all publicly owned waste treatment facilities are to provide at a minimum secondary level treatment, all industrial dischargers are to provide at a minimum the Best Practical Treatment (BPT) available. Where this level of treatment will not meet stream water quality standards, additional treatment is required. Estimated cost $71 billion. (Reference 42)
- By midyear 1983, all industries must utilize the Best Available Technology (BAT), and municipalities must provide BPT.
- By midyear 1985, all dischargers are to achieve "zero discharge."

Since the passage of the FWPCAA and the promulgation of standards by the Water Resources Council (Reference 58), there has been considerable research into the estimation of costs of achieving these goals. Congress had some information as to the monetary costs of achieving these goals, but had little information with which to estimate the benefits to be derived by achieving these goals. However, very little has been done to date to determine and document the level of national benefits for each level of water quality improvement. Some reasons for this scarcity of information are touched on below.

A short historical review of benefit studies can be found in an EPA Report to Congress (Reference 49). However, it is fair to state that the development and application of techniques to estimate either benefit or cost levels has been a direct result of the characteristics of our national decision making and budgeting system. The major effort has been on reducing the uncertainty in estimates of cost, whether it be the cost of a specific project, implementation of a water management plan or attainment of the goals specified in the 1972 FWPCAA. The initial thrust of research was in the better estimation of costs, which in turn led to a need to better estimate benefits.

Experience of Corps of Engineers planners, in the application of cost-benefit analysis typifies this phenomena (Reference S-2). Corps planners have become somewhat expert in estimating project costs and in identifying an adequate level of benefits to compensate for these costs. Cost estimation is a science, while estimation of benefits is an art.

There are some theoretical reasons for this problem. As pointed out by Abel and Tihansky (Reference 1):

> "Maximizing social welfare is a common objective of public programs. Unfortunately there are no direct measures of welfare....economists have... discovered criteria that could serve as conceptually and operationally meaningful proxies..."

The EPA, the Corps of Engineers, the Water Resources Council, and the Commission on Water Quality Criteria have each formulated techniques which would be used to develop such proxies and/or to estimate the level of benefits. Unfortunately, considerable debate continues as to the conceptual validity of these techniques (Reference 59), the application of the techniques (Reference 49), and the inferences based on these techniques (Reference 6 and 9). All that we can say with some sense of confidence is that private market transactions are not adequate proxies or measures of benefits (Reference 60).

The precise problem which has been infrequently addressed is the development of estimates of the national and regional benefits to be realized from the attainment of the water quality goals established in the 1972 FWPCAA. Estimates of such benefits are required because one criterion for water resource planning is national economic efficiency. The keystone for the determination of economic efficiency is cost benefit analysis and the estimation of benefits is necessary to such analysis.

The use of cost benefit techniques as precise policy making tools without appropriate measures of costs and benefits can produce two types of undesirable results.

> "One is the formulation of regulations (policies) as though they were based upon benefit-cost analysis, when in fact they were not. This is the case...when benefit-cost analysis becomes a rationalization of existing decisions rather than a guide to decisions. The other is the postponement of public action where manifest externalities are present until such a time is reached when precise calculations can be made." (Reference S-1)

However, the lack of such information does not mean that we must refrain from the development of policy. Baumol argues that given limited information on which to formulate public policy the "reasonable" course of action is

> "...to act on the basis of a set of minimum standards of acceptability. If, say, we treat the sulfur content of the atmosphere as one of the outputs of the economic system, it is not unreasonable to select some maximum level of this pollutant that is considered satisfactory and to seek to determine a tax on the offending inputs or outputs capable of achieving the chosen standard." (Reference 5)

According to Baumol, the advantages of this approach must be weighted against its shortcomings.

> "...the acceptability criterion approach does not dispose of the difficulties involved in finding a true optimum--rather it sweeps those difficulties under the rug. Even with pollution reduced to acceptable levels, there will remain the possibility that the (undiscovered) global optimum offers us a world far better than what we have managed to achieve--if only we know how to attain it. But if we permit ourselves to be paralyzed by councils of perfection we may have still greater cause for regret." (Reference 5)

It is an approach such as described above which has in fact been followed. Goals have been established and it now remains to refine the analysis in our attempt to determine a global optimum.

The science of economics provides a framework for determining the efficiency of resource allocations and therefore the economic desirablility of different actions or objectives. Several criteria for efficiency have been brought forth starting with the traditional concepts of welfare economics (Reference S-1) through to considerations of Pareto optimality (Reference S-3). However, all such criterion require, at some point, an estimation of both benefits and costs, and as reported by one economist,

> "There is good reason to believe that the social-welfare function is a philosopher's stone and does not exist in any real society." (Reference 15)

However, some solution is required, and the economics of environmental management provides some insights.

The problem exists because the environment is often treated as a free good, whereas it is not. As stated by Ayres and Kneese:

> "If waste assimilative capacity of the environment is scarce, the decentralized voluntary exchange process cannot be free of uncompensated technological external diseconomies unless (1) all inputs are fully converted into outputs,...and all final outputs are utterly destroyed... or (2) property rights are so arranged that all relevant environmental attributes are in private ownership and these rights are exchanged in competitive markets." (Reference 3).

Since neither of these conditions is feasible in the immediate future, it is necessary to fall back on cost benefit considerations of efficiency.

In summary, then, it can be seen that considerable research has been conducted into measures of efficiency concluding the benefit-cost analysis does provide the best mechanism for meeting that criterion. However, there is much less information available as to how both costs and benefits are to be identified and measured. This report attempts to analyze one aspect of cost estimization and minimization by examining the relationship between total investment cost, life cycle costs and the timing of water pollution control investments.

# APPENDIX D

## IRON AND STEEL MAKING, INDUSTRIAL PROCESS TECHNOLOGY CHANGES

Industrial pollution control costs may be substantially changed either through the development of new industrial processes or through major modifications in present processes and operations. For example, some industries have developed new recycling and re-use technologies in order to continue their operations in those areas where water shortages or price increases are occurring. In such cases economics alone dictated recycling.

Over the last few years due to the pollution control legislation, many industries have developed new processes and/or made major modifications to existing processes and operations. Under some circumstances it has been possible to make the necessary changes in a process and/or operating procedures without an excessive capital cost and/or product cost increases. However, in any case where the development and implementation cost of these new processes must be added to significant unamortized costs of existing processes, then industry is doubly burdened with the undepreciated previously invested capital. Thus, in some cases, the development of new technology may inflate the cost of the produce being manufactured and endanger the very existence of the industry.

As a part of this study of the cost of compliance timing, MATHEMATICA has examined the potential for technological innovation within a specific industry - Steel, and this Appendix describes how potential developments or process changes can influence compliance with the1972 FWPCAA water quality goals.

As a consequence of a consistent historic bias toward elimination of wastes as opposed to their prevention, to date much of the water pollution control technology has focused on "end-of-pipe" treatment. Recycling has been considered, but only within the context of constant basic steel-making technology. However, the potential to change the basic technology underlying the industrial processes and to significantly affect effluent quality, quantity and pollution control requirements must be considered. Each major pollution producing category is examined below.

Coke Manufacture -
Coke production from Bituminous coal (in some cases, small percentages or Anthracite or coke fines are added) is the first step in preparing the reducing agent for the conversion of iron ore to molten blast furnace metal for eventual decarbonization to stell. The coking operation is carried out in retort furnaces (called by-product coke ovens) and the process effluent waters carry small amounts of detrimental phenols and ammonia compounds. Efforts are being made to develop technology which destroys the phenols or otherwise removes them before discharging the effluent to the environment. This is not a simple technology and it may be 10 to 20 years before the removal of phenol becomes industry-wide.

By-product coke ovens are not industry-wide. Because of shortages of By-product coke over the last five to ten years, Beehive coke ovens are still in use. However, no water is required in Beehive ovens and, hence no water pollution, - only combustion gases causing atmospheric pollution.

As an alternative to coke ovens, technology development research is being carried on by a consortium of companies on a continuous coal preparation and coking process which, if successful, should eliminate the phenol and water quenching pollution problems. This, however, is a long-time development and even though commercially successful and economical, it would probably be twenty years or more before the process could be adopted industry-wide because of the large existing investment in By-product coking facilities. Even should this technology be economically available, it would not be applied in all cases as the coke produced by this process could not be substituted for Beehive or By-product coke.

In contrast, there is also research and development work going forward in pre-reduction using a fuel like oil, natural gas or hydrogen to produce a crude sponge iron. This sponge iron can then be converted to steel in the Electric Furnace or it may be used with scrap along with the regular charge in the blast furnace or basic oxygen processes. There are several such commercial furnaces known as the Hyl Process in operation in foreign countries including Mexico and Venezuela which use natural gas or the equivalent as the fluidizing and reducing media. According to the news media, Saudia Arabia, having abundant natural gas, has recently let a contract for a steel plant including the Hyl iron producing units. It is technologically possible to build and operate a steel plant without coke ovens and blast furnaces, using instead gaseous reduction units producing a crude sponge or pre-reduced iron. Electric steel making furnaces or basic oxygen furnaces are used for further processing. This technology is attractive in countries where there is cheap and abundant natural gas or petroleum products which can be converted into a reducing gas.

In addition to the gaseous reduction, there is also a R-N Process based on ore and coal and carried on in a rotary kiln. The process was developed in Germany and refined in the United States by National Lead and Republic Steel. The process has never become a serious competitor because of the apparent continuous furnace problems and the difficulty of separating the iron from the slag constituents.

Many processes are being considered to reduce the amount of coke required in a blast furnace or to eliminate the blast furnace entirely. Generally thses processes will be applied under unique conditions because of the need for a cheap gaseous reducing agent and because of the fact that the modern blast furnace, and its auxiliaries, is thermally a highly efficient metallurgical tool. This is especially so when it is combined with the basic oxygen process.

However, processes in which fine ore and coal would be pelletized followed by coking and pre-reduction in one step would be desirable. The pre-reduced pellets could be treated in a blast or electric furnace to produce metal. It would also be technologically sound to use a judicious amount of such pre-reduced material in the basic oxygen process, thus eliminating the pelletizing or sintering of the fine ore and the use of coke as such. (Coke fines or anthracite could be used as part or all of the reducing agent where available.) Variations of such a process have and probably are being investigated but as far as is known no large commercial units are in operation here or abroad. The development of commercial units for adoption by the industry on a large scale will probably be ten to twenty years or more in the future.

## Iron and Steel Making -

The most recent development in the steel making process is the gradual replacement of the open hearth furnace by the basic oxygen furnaces (BOF), also known as the basic oxygen process (BOP). It is estimated that about 80% of the steel now produced in the United States and worldwide is produced by this new process. Most of the remaining open hearths will probably be eliminated or placed on a standby basis within five to ten years. Because of the capital investment required for the BOP, and its auxiliaries and the production limitations, a few open hearth's may never be eliminated. However, the estimated 80% replacement has taken from early 1950 to early 1970, twenty years. Normally, it would take longer to make such a large change in a basic industry like steel; however, in spite of the large capital investment required, the changeover was brought about rather quickly by economics.

Another more recent development is the adoption of the electric furnace by a large segment of the industry. Some few companies which operated largely on scrap or specialties has used electric furnaces for many years, however, this recent large scale acceptance is due to the large accumulation of scrap, e.g., automobiles, trucks, etc., and the necessity for recycling. Recycling scrap can be satisfactorily handled and with scrap refined into steel by the electric furnace.

The adoption of continuous casting has increased the desirability of the electric furnace as a means to keep the molten steel hot for continuous casting operation. When BOP is used to supply continuous casting, should it be necessary to interupt the continuous casting program, it is then necessary to interfere with BOP operations.

However, only about 2 to 4% of the steel produced in the United States is cast by continuous casting so that the increased use of the electric furnace has been attributable to the ability to collect and prepare scrap for its use. Recent trends to scrap has led to increases in the price of scrap in the last two years, to the point that some electric furnaces are having trouble being competitive.

Iron and Steel Forming -
Probably the most difficult but yet the most significant development in the Iron and Steel Industry is in the forming process. Continuous steel casting was first developed in Europe in the late 1950's and early 1960's. Continuous casting provides significant savings both in fuel requirements and in the quantity and quality of steel produced. The process produces less scrap and scale and the yield of finished steel is increased from 2 to 4%, or more.

Basically, the process takes molten steel in large refractory lined ladles from the BOP or electric furnace and pours it into a holding pot or directly into a tundish (pour box) where the flow rate to a water-cooled copper mold is controlled. In passing through the mold a frozen layer of steel is formed which provides the shape and cross-sectional size of the ingot or slab. The partially frozen shape now passes into sets of water-cooled rollers where the water sprays continually extract the heat, freezing the remaining molten steel inside the shell. The rollers bend the ingot from a vertical direction as formed in the mold to a horizontal slab or ingot as a function of the shape of the mold. After the center is frozen the slab or ingot is cut by a moving saw to the desired length. The shapes are then stacked for further cooling if cold-rolled. For hot-rolling they are passed through a reheating oven to bring the slab to the required temperature.

While the casting process was first developed in the late 1950's in Europe, it was not until 1965 when the first experimental commercial size unit was introduced in the United States of America.

Conclusions -

Based on an analysis of the current technological trends and history of innovation in the industry as described above, the following conclusions may be drawn:

(1) The steel industry is characterized as requiring significant time periods between the development of a new process or major change in a current process and industry-wide implementation of that new technology. This time is in the order of 10 to 20 years in part because of proprietary reasons, but more so because of the large first-capital investments and the larger new-capital requirements. Because of these conditions, the requirements to meet the 1977 effluent standards in either 1977 or 1980 as set forth in the FWPCAA, cannot be achieved through modification of the steel making technologies.

(2) However, it does appear that over a longer period of time, ten years or more in some cases, the potential exists for significant reduction in the quantity of the water discharged and the concentration of objectionable contaminates therein.

# SUPPLEMENTAL REFERENCES

S-1 Feller, I. and Nelson, J. P. Economic Aspects of Noise Pollution, Pennsylvania State University, Center for the Study of Science Policy, April 1973.

S-2 Orlando, J.A. and Weber, E.W. Management of Uncertainty in Water Resource Planning, Final Report to Corps of Engineers, November, 1973.

S-3 Pigou, A.C. The Economics of Welfare, 4th edition, MacMillan, London, 1946.